LANDFIRE 2001 and 2008 Refresh

Geographic Area Report

Hawaiʻi

December 2011

Executive Summary

The LANDFIRE National project (LF_1.0.0) was successfully completed in 2009. The goal of LANDFIRE National was to generate consistent 2001 vintage 30 meter spatial data sets for all 50 states for fire and other natural resource applications. This report highlights results from the continuation of LANDFIRE as a program to update the spatial data layers through 2008. The focus of this phase of the program was to improve the data products and account for vegetation change across the landscape caused by wildland fire, fuel and vegetation treatments, and (or) management. In addition, changes caused by insects and disease, storms, invasive plants, and other natural or anthropogenic events were incorporated when data were available. This report describes the LANDFIRE 2001/2008 Refresh effort to update existing map layers to reflect more current conditions, focusing primarily on vegetation changes. The effort incorporated user feedback and new data, producing two comprehensive Refresh data product sets:

1. LANDFIRE 2001 Refresh (LF_1.0.5) enhanced LANDFIRE map layers by incorporating user feedback and additional data to provide a foundation to update data to 2008. It was also designed to provide users with a data set to help facilitate comparisons between 2001 and 2008 (i.e. Refresh LF_1.1.0) data sets.

2. LANDFIRE 2008 Refresh (LF_1.1.0) updated map layers to reflect vegetation changes and disturbances that occurred between 1999 and 2008.

In this report, we (1) address the background and provide details pertaining to why there are two Refresh data sets, (2) explain the requirements, planning, and procedures behind the completion and delivery of the updated products for each of the data product sets, (3) show and describe results, and (4) provide case studies illustrating the performance of LANDFIRE National, LANDFIRE 2001 Refresh and LANDFIRE 2008 Refresh (LF_1.1.0) data products on some example wildland fires.

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1.0 Introduction

1.1 LANDFIRE Program

LANDFIRE (LF), also known as Landscape Fire and Resource Management Planning Tools, is a joint program between the wildland fire management programs of the United States Department of Agriculture (USDA) Forest Service (USFS) and the United States Department of the Interior (DOI) including the following bureaus: the U.S. Geological Survey (USGS), the Bureau of Indian Affairs, the Bureau of Land Management (BLM), the Fish and Wildlife Service (FWS), and the National Park Service (NPS). The Nature Conservancy (TNC) serves as a cooperating partner. LF applies consistent methodologies and processes to create comprehensive spatial data and models describing vegetation and wildland fire/fuel characteristics across the United States. Mapped data products are based on Landsat satellite imagery and an extensive database of field-reference data, including USFS Forest Inventory Analysis (FIA) data.

LF provides the first implementation of methodologies and processes to develop and combine spatial vegetation and fire information consistently across the entire United States. Such a suite of integrated vegetation, fuel, and fire regime data sets was never previously created by the public or private sectors. LF data products facilitate national and regional (large landscape level) fire planning activities and the reporting of wildland fire management activities. LF products provide managers with the data needed for collaborative, landscape-scale, cross-boundary, interagency planning and implementation. LF data support land management to 1) identify fuel where fire hazards and fire risks to local communities may be located, 2) identify vegetation and fuel conditions where rehabilitation may benefit fire-dependent landscapes, 3) prioritize resources for national budget formulation and allocation, and 4) enhance management knowledge of fire behavior to improve firefighting safety. Programs within the wildland fire community that use LF data include the National Cohesive Wildland Fire Management Strategy, the Wildland Fire Decision Support System, Fire Program Analysis, and the Hazardous Fuel Prioritization and Allocation System.

While LF has proven highly valuable for the wildland fire community, it also provides value for other land management disciplines. LF data products provide an informational foundation that supports many diverse applications, including land management planning, environmental analyses, biological evaluations, monitoring, and resource assessments. Moreover, LF data are being considered as a key information input to a range of Federal interagency carbon sequestration and climate research initiatives. LF products are used in the land and resource management domains for setting strategic direction, supporting resource and staffing determinations, designing conservation management activities, and assessing risks to the environment and communities.

1.2 LANDFIRE Versions

In an effort to address user feedback and leadership direction, the LF team started from the base collection of data products developed during the LF National Project (circa 2001) to provide an updated collection of LF products. As such, different versions of LF data products were developed, requiring the creation of a data versioning specification. The data versioning table, available on the LF website (http://www.landfire.gov/version_comparison.php), assists users in understanding the differences among the various versions of LF data available on the LF Data Distribution Site (DDS). When LF data products are updated in the future, most of the versions currently available will be removed from the DDS and archived. Previous versions will be made available upon request. At any given point in time, there will be at most three versions of the data products available. These will remain available for download on the DDS until the next product update has been completed.

1.2.1 LANDFIRE National (LF_1.0.0) circa 2001

LF National (LF_1.0.0) constitutes the first complete LF mapping of all geospatial data products for the Nation. LF National was a five-year project that incorporated Landsat imagery from 1999 through 2003 ("(circa 2001")) and in 2009, delivered data on vegetation characteristics and condition, fire behavior and effects, fuel models, historical fire regimes, and fire regime conditions class at the landscape scale. In this report, we refer to this data set simply as "LANDFIRE National" or "LF National." The final deliverables for LF National included all of the layers required to run fire behavior models, such as the Fire Area Simulator (FARSITE; Finney, 2004). Methods used were consistent and repeatable nationwide across all ownerships. The consistent and comprehensive nature of LF National methods ensured that data were nationally relevant, while the 30-meter grid resolution assured that data had local application. A modified suite of the LF National data products was delivered for Alaska and Hawaiʻi.

1.2.2 LANDFIRE 2001 (LF_1.0.5) and 2008 (LF_1.1.0) Refresh

The LF 2001/2008 Refresh represents the initial effort to enhance and update LF layers to maintain the currency of the data sets across all 50 states. These versions were produced in tandem, starting in fall 2009 with the LF 2001 Refresh (LF_1.0.5), and finishing with the LF 2008 Refresh (LF_1.1.0) in calendar year 2011.

LF 2001/2008 enhancements and updates were developed to facilitate comparative analyses, evaluate trends, and potentially monitor changes over time. In this report, we use the following simplified terminology.

When the enhancement and update segments are referred to individually, we use:

- (enhancements) "LANDFIRE 2001" or "LF 2001" for LANDFIRE 2001 Refresh (LF_1.0.5)
- (updates) "LANDFIRE 2008" or "LF 2008" for LANDFIRE 2008 Refresh (LF_1.1.0)

When we refer to both of these segments together in a generic fashion, we use:

- "LANDFIRE 2001 and 2008" or "LANDFIRE 2001/2008"
- "LF 2001 and LF 2008" or "LF 2001/2008"

The LF 2001 version was implemented to enhance the LF National data set and provide a foundation upon which to build the updated geospatial data set.

The LF 2008 version was implemented to update the LF National data set to reflect changes from recent (1999-2008) natural disturbances (such as wildland fires) and management activities using Landsat imagery.

1.3 LANDFIRE 2001/2008

The LF 2001 and LF 2008 components of the LF Program sustain and extend the investment value of the original LF National data products with enhancements and updates to the LF spatial data suite. LF 2001 addressed vegetation discrepancies and areas of concern detected after the initial mapping effort.

LF 2008 focused on updates to the suite of LF data products to reflect 2008 conditions This focus was on updating landscape-level vegetation changes, such as those resulting from wildland fire, where data were available that occurred in the years from 1999 - 2008. A collection of recent natural disturbance and land management activities was collected and stored in a spatial database. These products were combined along with other data sets to update existing vegetation and fuel layers. These updated vegetation and fuels layers were then used to update other LF data products. To update products, LF 2001/2008 leveraged information and comments received through various sources, such as the LF help desk (http://www.landfire.gov/contactus.php), after action reviews, fuel calibration workshops, and lessons learned examples. LF 2001/2008 products have been used as inputs to strategic wildland fire management decision support systems and are expected to improve the relevance and reliability of the outcomes generated by these systems.

Nine geographic areas (GeoAreas; Figure 1) were defined to include all of the original mapping zones used from the National Land Cover Database (NLCD; based loosely on Omernik, 1987) for use in the LF National effort. The application of mapping zones as a pre-classification stratification method has been used in many mapping approaches (Homer et al. 1997; Homer et al. 2004). Research has shown that carefully defined mapping zones maximize spectral differentiation, provide a means to facilitate partitioning the workload into logical units, simplify post-classification modeling and improve classification accuracy (Homer et al. 2004). The GeoAreas were not intended to represent standardized analysis units or reporting extents. The primary purpose of the GeoAreas and mapping zones was to define ecologically relevant divisions for data acquisition and production planning.

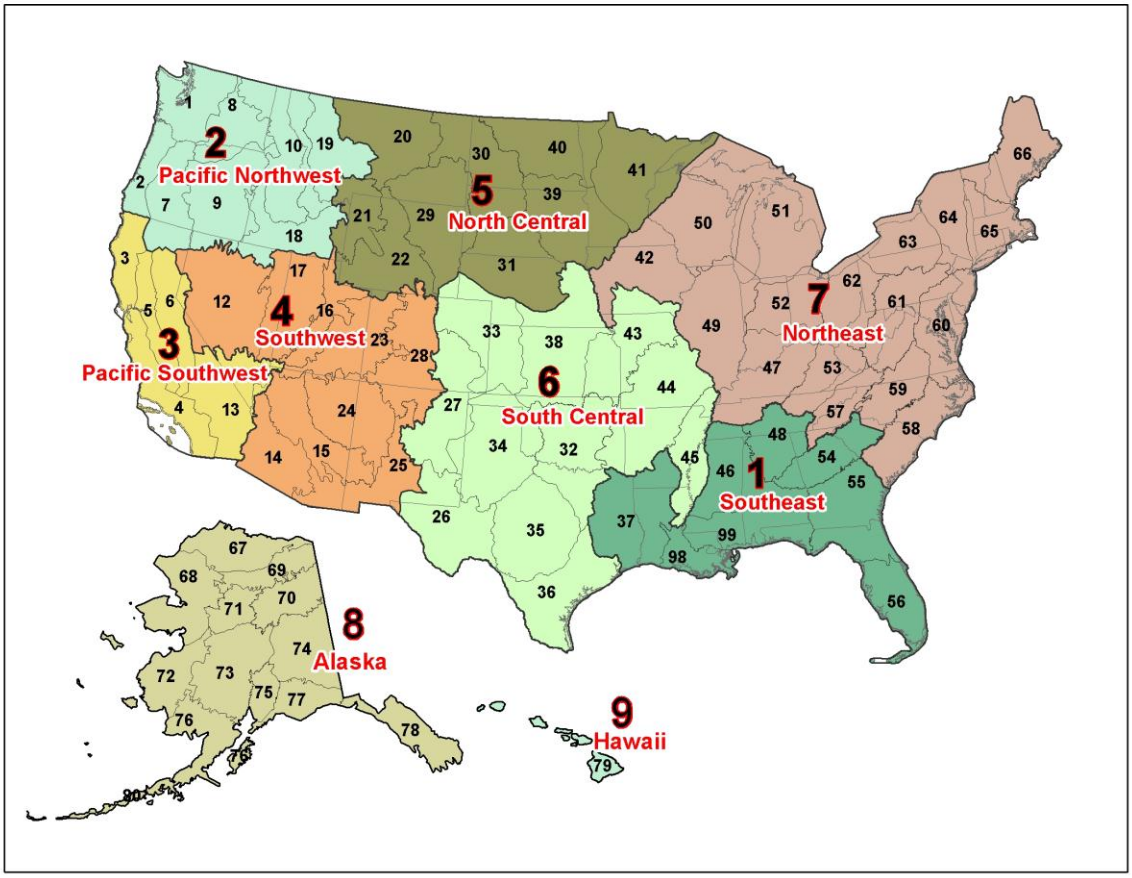

Figure 1 – Map of LF 2001/2008 GeoAreas according to the schedule. This image shows the nine GeoArea boundaries, which are comprised of National Land Cover Database 2001 mapping zones (numbered units), state boundaries are included for reference. GeoArea numbers and corresponding colors relate to the schedule in Table 1below.

1.4 LANDFIRE 2001/2008Statement of Work and Work Breakdown Structure

LF 2001/2008 used conventional best practices in project and program management to address the organizational structure, scheduling, and implementation procedures. The effort was faced with uncertainties common to many initiatives in the public and private sectors with regard to funding availability for elements within and outside of the scope of the program, contract acquisition, and prioritization of requirements that would shape the final suite of deliverables.

A statement of work (SOW) approach was used to define the scope of LF 2001/2008 and the data products to be delivered. In essence, the SOW included the development of comprehensive documentation describing the general methodological approach required to develop the suite of LF 2001/2008 intermediate and final products (deliverables). The SOW also included guidelines for quality assurance and quality control procedures, program management and program performance standards, estimates of overall duration, and an independent estimate of cost to the government for the defined scope of work.

Introduction

A primary element of the SOW was a structured index and definition of work segments and deliverable-scheduled milestones. This structure is referred to as a Work Breakdown Structure (WBS) – also a standard best practice in program planning and management – and is used for effective organization and management of work activities. The SOW document and WBS organization drew upon lessons learned and program management artifacts developed during the completion of the LF National project and the LF 2007 Rapid Refresh project. A summary display of the actual project results in terms of scheduled initiation and completion of project milestones is provided in Figure 2 below. A description of the project milestones (such as GeoAreas and Group A and Group B product segments as outlined in (Table 1) is provided in detail in section 1.5 of this report.

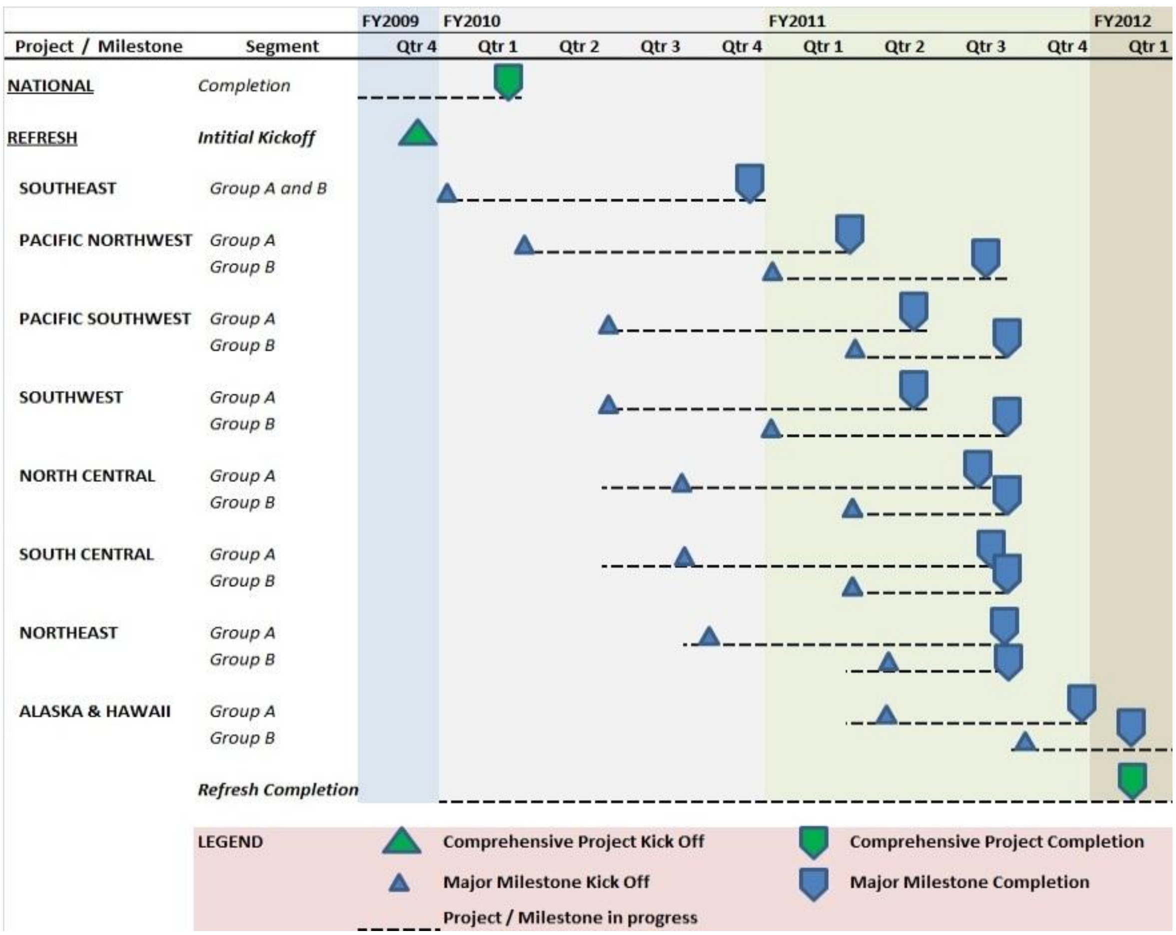

Figure 2 – LF 2001/2008 Gantt chart. This is a summary display of the actual results of the start and finish dates of the milestones and segments [such as GeoArea and Group A and Group B products]. These milestones and segments comprise the WBS discussed in Section 1.4.

The LF 2001/2008 effort was challenged by external factors such as mandatory work stoppages related to contractual reviews at the USFS and access to a range of qualified vendors through contract vehicles at both DOI component agencies and the USFS. Moreover, evolving management requirements resulted in longer periods of time required to complete processes for conducting full and open competitive bidding and finalizing vendor selection and formal work kickoff. Nonetheless, the use of comprehensive SOW documentation and WBS organization permitted the LF Program to segment certain elements of development work and allocate these elements to vendor organizations that were best qualified and able to complete the LF 2001/2008 work at an optimal combination of cost, quality, and schedule performance.

At the inception of the LF 2001/2008 effort, there was a tight interdependency in scheduling between LF 2001/2008 and the Monitoring Trends in Burn Severity (MTBS) project. As noted in detail throughout this GeoArea report, LF 2001/2008 used data such as the MTBS mapping products to characterize the landscape changes reflected in LF 2001/2008 data layers. Thus, the structure of LF 2001/2008 production activities as well as product releases were linked to the organization of the original MTBS production schedule, which was segmented by geographic regions across the conterminous United States (CONUS).

1.5 LANDFIRE 2001/2008 Spatial Products

LF 2001/2008 was originally estimated to span 24 months and involve over 500 unique tasks to deliver updated LF data layers. The update was highly dependent upon field data in the form of landscape change polygons and other information regarding landscape conditions. LF partitioned the delivery of the updated LF 2001/2008 products into two segments, "Group A" and "Group B," to facilitate management direction and the fulfillment of user needs. The staggered release of products by GeoArea (Table 1) and grouping of data products (Table 2) was determined to be the most practical approach with respect to scope limitations, cost considerations, and contractual circumstances.

Table 1 – LF 2001/2008 product delivery schedule listing the nine GeoAreas as represented above in Figure 1 and delineating delivery of “Group A” and Group “B” data sets

Table 1- LF 2001/2008 Schedule		
Geographic Area	**Group A**	**Group B**
Southeast	4th Qtr. 2010	4th Qtr. 2010
Pacific Northwest	1st Qtr. 2011	3rd Qtr. 2011
Pacific Southwest	2nd Qtr. 2011	3rd Qtr. 2011
Southwest	2nd Qtr. 2011	3rd Qtr. 2011
North Central	2nd Qtr. 2011	3rd Qtr. 2011
South Central	3rd Qtr. 2011	3rd Qtr. 2011
Northeast	3rd Qtr. 2011	3rd Qtr. 2011
Alaska	3rd Qtr. 2011	4th Qtr. 2011
Hawaiʻi	3rd Qtr. 2011	4th Qtr. 2011

Table 2 - LF 2001/2008 list of data products and how they were grouped (Group A and Group B) to facilitate management direction and user needs.

Table 2- LF 2001/2008 Products and Groupings	
Group A	**Group B**
Fire Behavior Fuel Model 13 (FBFM13)	Biophysical Settings (BpS)
Fire Behavior Fuel Model 40 (FBFM 40)	Vegetation Condition Class (VCC)
Canadian Forest Fire Danger Rating System (CFFDRS) (Alaska Only)	Vegetation Departure Index (VDEP)
Forest Canopy Bulk Density (CBD)	Fire Regime Groups (FRG)
Forest Canopy Base Height (CBH)	Mean Fire Return Interval (MFRI)
Forest Canopy Cover (CC)	Percent Low Severity Fire (PLS)
Forest Canopy Height (CH)	Percent Mixed Severity Fire (PMS)
Fuel Characteristic Classification System Fuelbeds (FCCS)	Percent Replacement Severity Fire (PRS)
Existing Vegetation Type (EVT)	Fuel Loading Models (FLM) (Excluding Hawaiʻi)
Existing Vegetation Cover (EVC)	Succession Classes (SCLASS)
Existing Vegetation Height (EVH)	

2.0 LANDFIRE 2001 and 2008 Methods and Results

2.1 Geographic Area Description

The Hawaiʻi (HI) GeoArea consists of one mapping zone encompassing the eight main islands in the State of Hawaiʻi; an area greater than 5.2 million acres.

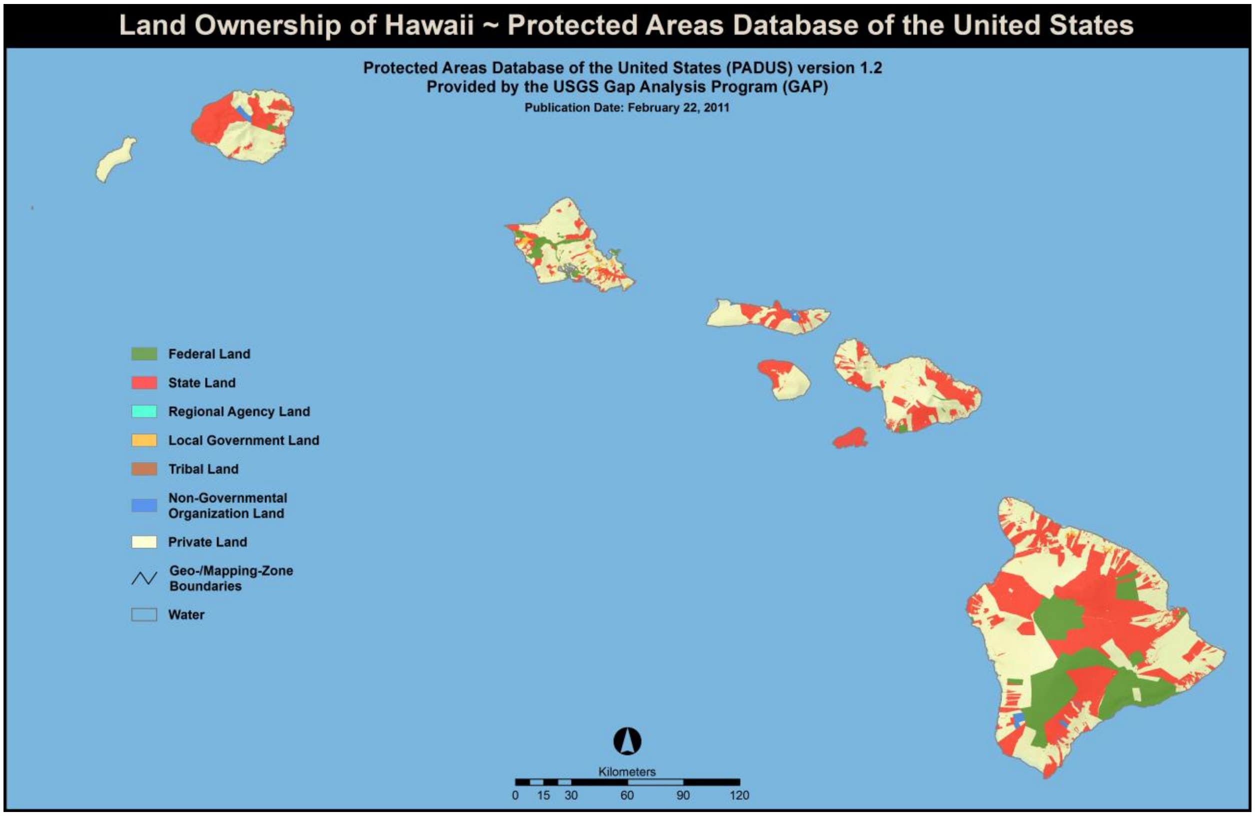

Figure 3 – Land ownership categories for the HI GeoArea.

Within a given GeoArea, land ownership is important because the condition of the landscape, including disturbances, may be a direct result of ownership mission and management activities. A summary of land ownership segmentation across the HI GeoArea is provided in Table 3 and shown in Figure 3

Table 3 – Categories of land ownership, number of acres, and percentages of total GeoArea by category for the LF HI GeoArea.

Table 3. Acreage of Land Ownership Categories for the HI GeoArea.		
Land Ownership	**Acres**	**Percent of GeoArea**
Federal Government	642,034	12.2
Government and/or Private	193,398	3.7
Local Government	26,923	0.5
Private	1,994,671	37.9
State Government	1,263,246	24.0
Water	1,143,692	21.7
Total	5,263,964	100.0

2.2 LANDFIRE Reference Database

2.2.1 Product Description

LF 2008 mapping was supported by a large database of field-referenced data. The LANDFIRE Reference Database (LFRDB) includes vegetation and fuel data from over 800,000 geo-referenced sampling units located throughout the United States. These data were amassed from numerous sources, and, in large part, from existing information resources of outside entities, such as the USGS National Gap Analysis Program (GAP) and state natural heritage programs. Vegetation data drawn from these sources and used by LF include natural community occurrence records, estimates of canopy cover and height per plant taxon, and measurements (such as diameter, height, crown ratio, crown class, and density) of individual trees. Fuel data included biomass estimates of Downed Woody Material (DWM), percent cover and height of shrub and herb layers, and canopy base height estimates. Digital photos of the sampled units, when available, were archived.

A subset of the full suite of field-sampled data used in the production of LF deliverables is available for public access, as stipulated in the 2004 LF Executive Charter. In accordance with agreements between LF and its data contributors, certain proprietary or otherwise sensitive data were removed to create this publically available version of the LFRDB. There are over 275,000 sampling units from 260 different sources located throughout the United States available for public use.

2.2.2 LANDFIRE Reference Database Update Process

The following is a summary of key steps used by the LF production team to complete the LFRDB component of LF 2001/2008. These methods were subject to revision and update upon the completion of all LF 2001/2008 GeoArea processing

- acquired geo-referenced, field-sampled vegetation and fuel data from existing national and local programs - this work required extensive communication with representatives of governmental and non-governmental entities throughout the U.S.
- maintained a catalog and archive of all acquired data and metadata in their original formats using the existing LF data-catalog template and file structure
- assessed and prepared data for LF processing - this required an inventory of the geospatial data (in tabular format or as shapefiles, coverages, geodatabases, etc.) with regard to distribution and

information content and removal of records with irreconcilable geospatial or information errors/omissions

- converted relevant/viable data into LF format such that they conformed to standards defined in the data dictionaries for the AutoKey Database to accurately assign EVT to plots that have species composition (species and cover) attributes and LFRDB - this required using intermediate to advanced techniques for relational database management, manipulation and management of point and vector geospatial data, and regular documentation of data-conversion processes and quality-control measures
- acquired and incorporated all ancillary spatial data needed for LF production into the LFRDB (such as data extracted from LF base and product layers)
- derived and incorporated into the LFRDB any attributes necessary for LF production but not acquired as part of the original data sets - this included the derivation of canopy cover and height estimates from tree records, fuel loading estimates from DWM records, un-compacted crown ratios from compacted crown ratios, vegetation map-unit assignments from the Ecological Systems AutoKey, canopy fuel attributes from FuelCalc (Reinhardt, 2006) (a tool to compute surface and canopy fuel loads and characteristics from inventory data)
- checked for information and spatial errors as detailed in the LFRDB Quality Assurance (QA) checklist, and, once removed or appropriately identified, distributed the inaugural LFRDB for LF production
- maintained and updated the LFRDB after the inaugural posting by archiving relevant LF production information, including results of Quality Assurance / Quality Control (QA/QC) on LFRDB records performed by mapping teams and additional data as requested/permitted by LF mapping teams and leadership

2.2.3 LANDFIRE Reference Database Update Results

Final deliverables for the HI GeoArea consisted of (1) a catalog (spreadsheet) and archive (file system) of all acquired data, (2) an AutoKey Database (Microsoft Access© database) to quickly and accurately assign EVT to plots that have species composition (species and cover) attributes for the HI GeoArea, (3) an LFRDB (Microsoft Access© database) for the HI GeoArea, and (4) documentation of data conversion processes and QC measures taken during the data-loading stages.

The final LFRDB product for the HI GeoArea contains over 3,800 samples of vegetation and fuel data compiled from many different sources:

- 99% of data were submitted in response to the LF data call (http://www.landfire.gov/participate_refdata.php) and 1% of data were acquired by LF personnel through direct data sharing agreements, websites, or agency database systems
- 316 sampling events were added to the HI LFRDB for Refresh from the FWS that were collected for the Hawaiʻi Forest Bird Survey
- 16 different sources of data were contributed by Federal, State, and private entities.
- A total of 3,822 geo-referenced sampling events were included in the HI LFRDB

Major data contributions can be credited to the USGS, NPS and FWS. The remainder came from State and multi-agency contributions. Table 4 shows a breakdown of the data contribution profile for the HI LFRDB.

Table 4 – Data contribution profile for the HI LANDFIRE Reference Data Base.

Table 4 HI LANDFIRE Reference Database Data Contributions		
Data Contribution Profile	**Samples**	**Percent**
USGS	1,822	47.7
State	753	19.7
Multi Agency	545	14.2
NPS	386	10.1
FWS	316	8.3
USFS	0	0
Total	3,822	100

The LFRDB team incorporated additional vegetation data into the existing LFRDB, including information on community occurrence, species composition, and vegetation structure, to improve and update several LF 2001/2008 data products. Table 5 provides a summary of data types by percent distribution for the HI GeoArea. Community Occurrence data include natural community or cover type classifications, Species Composition data include canopy cover estimates per plant taxon, and Vegetation Structure data include height measurements per life form or plant taxon.

Table 5– Percent distribution of data types for HI LANDFIRE Reference Data Base.

Table 5. HI LANDFIRE Reference Database Plot Summary		
Data Type	**Samples**	**Percent ***
Community Occurrence Records	2,746	61.7
Species Composition	760	17.1
Vegetation Structure	943	21.2

**Percent occurrence of the listed data types within the LFRDB. The percentages do not total to 100% because a plot may have more than one data type. For example, a plot may have both species composition and fuel data whereas another plot may have only community occurrence records. The 4,714 new FIA plots that were added to the LFRDB provided species composition, structure, and fuel data, but not the other data types listed.*

2.3 Biophysical Settings

2.3.1 Product Description

The Biophysical Settings (BpS) layer represents the vegetation that was likely to have been dominant on the landscape prior to Polynesian settlement and is based on both the biophysical environment and an approximation of the historical disturbance regime. BpS is a refinement of the Environmental Site Potential (ESP) layer. In this update, we attempted to incorporate current scientific knowledge regarding the functioning of ecological processes, such as fire, in the centuries preceding human influence. Map unit labels were based on NatureServe's (NS) Ecological Systems classification; a nationally consistent set of mid-scale ecological units (Comer et al. 2003).

LF used these classification units to describe BpS, which differed from their intended use as units of existing vegetation. As used in LF, map unit names represent the natural plant communities that were likely to have been present during the reference period. Each BpS map unit was matched with a model of vegetation succession. The LF BpS concept is similar to the concept of potential natural vegetation groups used in mapping and modeling efforts related to Fire Regime Condition Class (FRCC; Schmidt et al. 2002; www.frcc.gov).

2.3.2 Biophysical Settings Layer Enhancements

The LF 2001/2008 BpS layer for Hawai'i was modified slightly to match changes to the EVT layer through a rectification process. This ensured that the EVT and BpS layers were compatible with each other and the vegetation transition process.

2.3.3 Fire Regime Products

Five layers [MFRI, PLS, PMS, PRS, and FRG] Mean Return Interval (MFRI), Percent of Low Severity (PLS) fire, Percent of Mixed Severity (PMS) fire, Percent Replacement Severity (PRS) fire, and Fire Regime Groups (FRG)] characterizing modeled historical fire regimes were produced based on the BpS and linkage with the Refresh Model Tracker (RMT). This linkage provides the probability of replacement, mixed, and surface fires. MFRI was calculated as the reciprocal of the sum of these probabilities (which is the probability of fire of any severity), grouped into classes and then combined with the non-vegetated types from the Succession Class (SCLASS) layer. The PLS, PMS, and PRS layers were calculated respectively as the ratio of the probability of surface, mixed, and replacement fires to the probability of any fire. The FRG was based on a combination of the MFRI and average fire severity from the FRCC Guidebook (Barrett et. al 2010), as displayed in Table 6. The FRG's for Hawaii are depicted in a map graphic in Figure 4. The area mapped in each FRG for LF National and LF 2001 is displayed in Table 7.

Table 6– The Fire Regime Groups by frequency and Percent Replacement Severity Fire for vegetation types within each regime as described in the FRCC Guidebook.

Table 6. Fire Regime Groups, Frequency, and Severity		
Fire Regime Group Name	**Frequency (years)**	**Severity**
FRG I	0-35	PRS < 75
FRG II	0-35	PRS >= 75
FRG III	35-200	PRS < 75
FRG IV	35-200	PRS >= 75
FRG V	200+	All

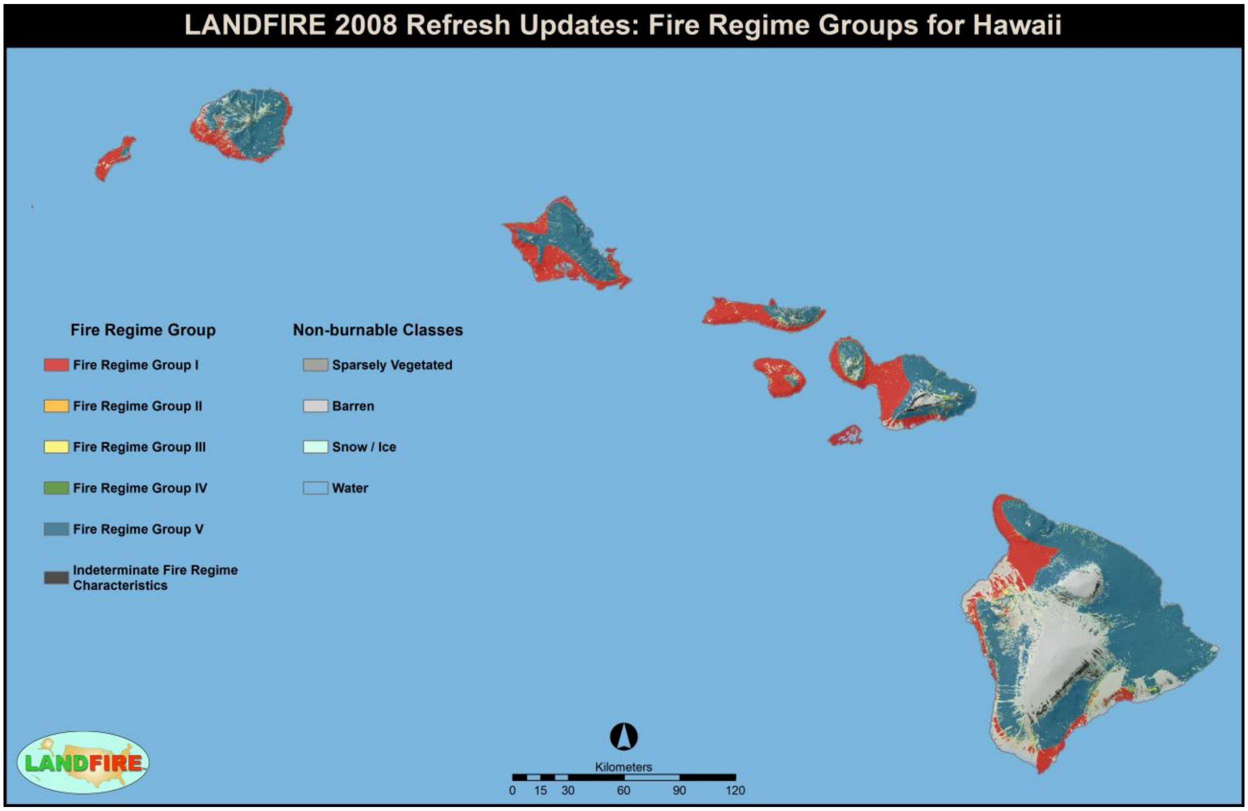

Figure 4 – Map of the HI landscape depicting LF Fire Regime Groups in the absence of modern human intervention with possible aboriginal fire use.

Table 7 – Comparison of acreage mapped and percent change by Fire Regime Groups in LF National and LF 2001 versions of LF data.

Table 7. Fire Regime Group Comparison			
Fire Regime Group Name	**LF National (acres)**	**LF 2001 (acres)**	**Percent Change**
FRG I	987,841	988,183	0.03
FRG III	28,819	28,819	0
FRG V	2,157,902	2,157,253	-0.03
Water*	1,143,681	1,007,950	-11.87
Barren	726,066	726,639	0.08
Indeterminate Fire Regime	222,263	221,985	-0.13

** The difference in the water coverage is attributed to the decreased extent in which ocean was mapped in LF 2001/LF 2008*

2.4 Disturbance Mapping

2.4.1 Product Description

LF disturbance data were developed to provide temporal and spatial information related to landscape change in order to determine vegetation transitions over time and make subsequent updates to LF vegetation, fuel, and other data. Disturbance data include attributes associated with disturbance year, type, and severity.

2.4.2 Disturbance Mapping Objectives

Changes in the landscape are pervasive and occur continually. For LF data to remain current, a process is needed to integrate spatial temporal landscape changes into the suite of LF products.

The objective of this process was to map the location, extent, type, and severity of major disturbances for the entire United States. To achieve this objective, several data sets needed to be integrated into one product. Not all types of data were available in all areas. The disturbance mapping process was performed at the LF mapping zone scale.

2.4.3 Disturbance Mapping Process

Disturbance mapping in Hawaiʻi was limited to combining MTBS and locally-contributed fire perimeter polygons. Burn severity was determined from MTBS or from local knowledge of the individual fires. Time since disturbance was categorized into three time steps:

- 1 year post disturbance
- 2-5 years post disturbance
- 6-10 years post disturbance

Three attributes (disturbance type, severity, time since disturbance) were combined to create the vegetation disturbance (VDist2008) and fuel disturbance (FDist2008) layers. Additionally, exotic herbaceous height estimates were included in the FDist2008 layer to facilitate surface fuel model assignments where exotic grasses were present and substantially affected surface fire behavior.

2.4.4 Disturbance Mapping Results

Disturbance categories were mapped and tabulated for the entire HI GeoArea (Table 8). Across all lands, 4 percent of the GeoArea was disturbed from 1999 to 2008, leaving 96 percent undisturbed. On Federal Lands, 6 percent of the land area experienced disturbance during this time period. The disturbances for Hawaii are depicted in a map graphic in Figure 5. Fire was the only disturbance mapped in this GeoArea, the area and severity of fire disturbances are listed in Table 9.

Table 8 – Categories of land ownership divided between areas with and without disturbance with associated percentages of ownership for the HI GeoArea and acres.

Table 8. Disturbance Acreage by Land Ownership			
Land Ownership	**Category**	**Acres**	**Percent Ownership**
All Lands	No Disturbance	5,050,732	96
All Lands	All Disturbances	213,233	4
Federal Lands	No Disturbance	606,088	94
Federal Lands	All Disturbances	35,946	6

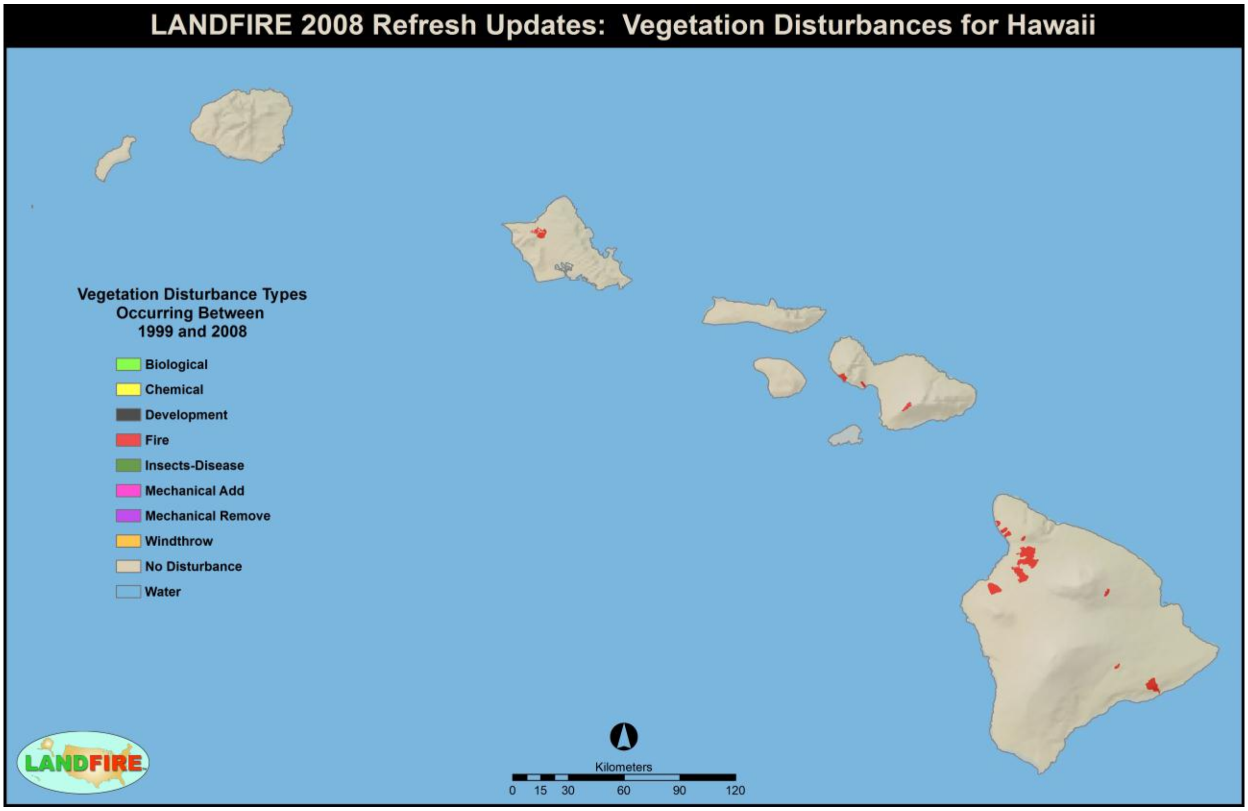

Figure 5 – Map of vegetation disturbance types (prescribed fire, wildfire, and wildland fire) for the HI GeoArea from 1999 to 2008.

Table 9 – Number of acres affected by fire disturbance with severity class information and the period of years since disturbance between for the HI GeoArea.

Table 9. Area Affected by Fire Disturbance			
Category	**Severity**	**Time Since Disturbance**	**Acres**
Fire	Low	One Year	2,919
Fire	Low	Two to Five Years	1,169
Fire	Low	Six to Ten Years	4,364
Fire	Moderate	Two to Five Years	1,039
Fire	High	One Year	1,369
Fire	High	Two to Five Years	4,090
Fire	High	Six to Ten Years	3,462

2.5 Existing Vegetation

2.5.1 Product Description

The existing vegetation layers for each LF mapping zone include: Existing Vegetation Type (EVT), Existing Vegetation Cover (EVC), and Existing Vegetation Height (EVH). All three layers were originally mapped using predictive landscape models based on extensive field-referenced data, satellite imagery, biophysical gradient predictor layers, and classification and regression tree classification trees. These existing vegetation layers were edited and refined as part of LF 2001/2008. The EVT layer represents the current dominant vegetation using map units derived from NS's Ecological Systems vegetation classification. The EVC layer represents the average percent cover of existing vegetation for a 30 meter grid cell. The EVH layer represents the average height of the dominant/co-dominant vegetation for a 30 meter grid cell.

2.5.2 LF 2001: Enhancements to Existing Vegetation Products

To improve their representation in several specific areas, the existing vegetation type and structure products were modified based on local expert opinion. In Figure 6 LF 2001 EVT is depicted. The EVT's are grouped by National Vegetation Classification Standard (NVCS) Subclass to assist with interpretation. In Figure 7, a map graphic depicts EVC. Lastly, LF 2001 EVH is depicted in Figure 8.

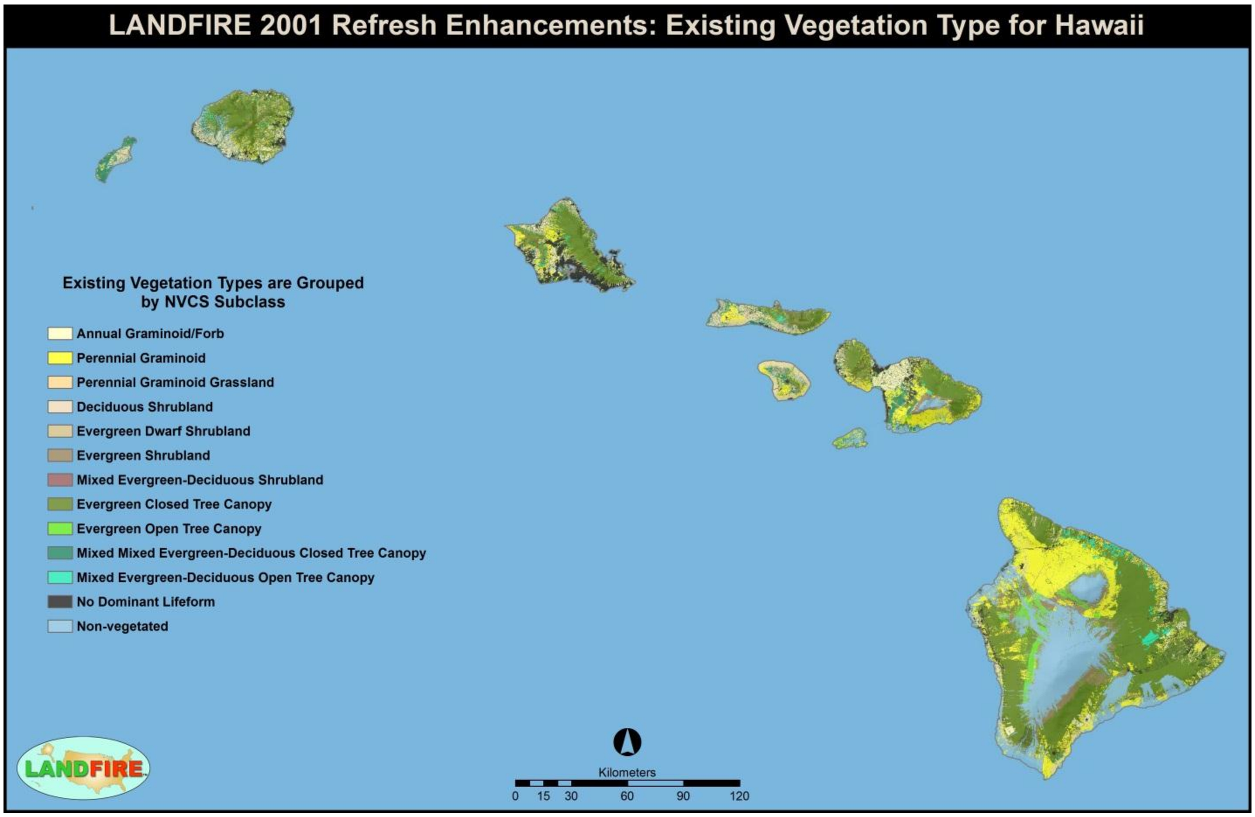

Figure 6 – Map of Existing Vegetation Type layer that was enhanced as part of the LF 2001 updates by incorporating user feedback and additional data.

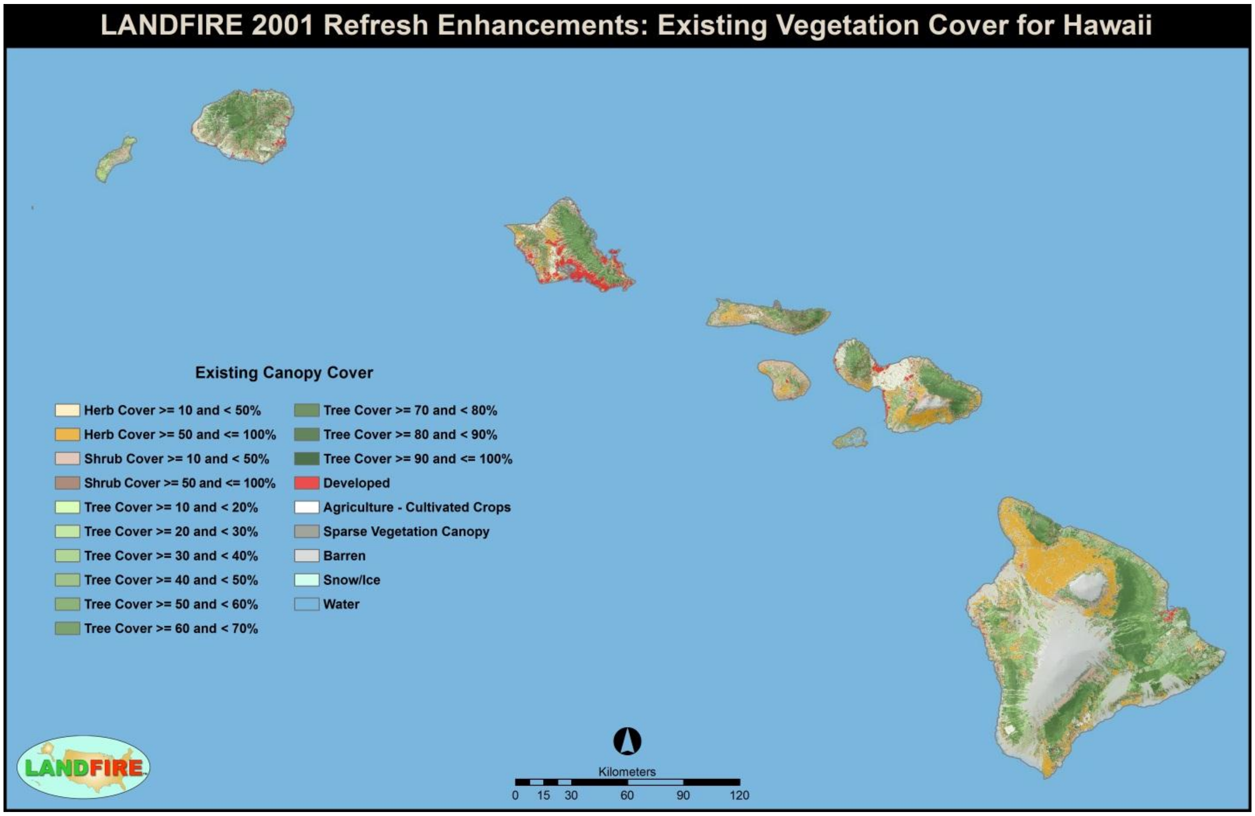

Figure 7 – Map of Existing Vegetation Cover layer that was enhanced as part of the LF 2001 update by incorporating user feedback.

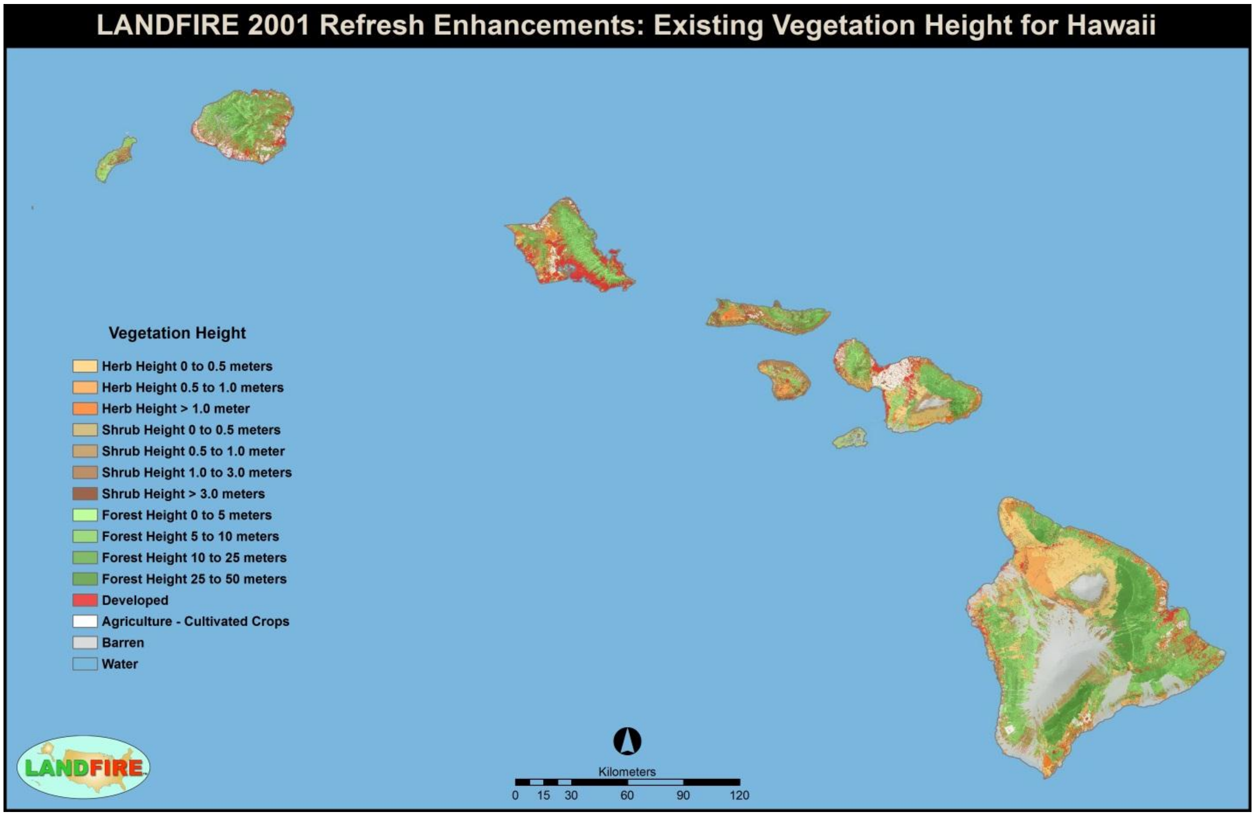

Figure 8 – Map of Existing Vegetation Height layer that was enhanced as part of the LF 2001 update by incorporating user feedback and additional data. These data provided a foundation upon which to create LF 2008.

2.5.3 LANDFIRE 2008: Updates to Existing Vegetation Products

The primary focus for updating the LF existing vegetation layers was to characterize disturbance activities from 1999 - 2008. Additionally, the update included changes within these disturbance areas due to tree growth and regeneration.

As discussed in section 2.4, disturbance mapping for LF 2008 included data derived in part from MTBS and the LF 2001/2008 Events data contribution. These data were used to produce disturbance maps identifying type, location, and severity.

The disturbance mapping identified areas where EVT, EVC, and EVH needed to be transitioned (updated) into new vegetation classes. Vegetation transitions were determined through literature sources and expert opinion for each EVT, EVH, and EVC combination based on the severity and time since each fire disturbance. These transitions were applied to the LF2001 layers to produce the LF2008 existing vegetation data.

Information from a variety of sources was used to inform vegetation transition assignments. Low severity fire did not affect EVT for any vegetation types. Moderate severity fire was considered stand replacing in exotic deciduous shrublands, causing a transition to an exotic herbaceous class. All other moderate severity fires were considered non-stand replacing and did not affect EVT. High severity fires were considered stand replacing for all vegetation types. For all fires occurring between 0-5 years, EVT was transitioned to an herbaceous class. For fires older than 5 years, EVT was transitioned to a shrubland type. EVC and EVH were updated based on the time since disturbance for those areas where the EVT lifeform was modified.

Depicted in Figure 9 is a map graphic of LF 2008 EVT. The EVT's are grouped by NVCS Subclass to assist with interpretation. Table 10 displays the corresponding changes in land area mapped to each EVT between LF 2001 and LF 2008. Likewise, matching changes for EVC LF 2001 and LF 2008 are displayed in Table 11 and depicted in Figure 10. Lastly, the affects to EVH attributed to the disturbances are depicted in Figure 11 and the differences between LF 2001 and LF 2008 are displayed in Table 12.

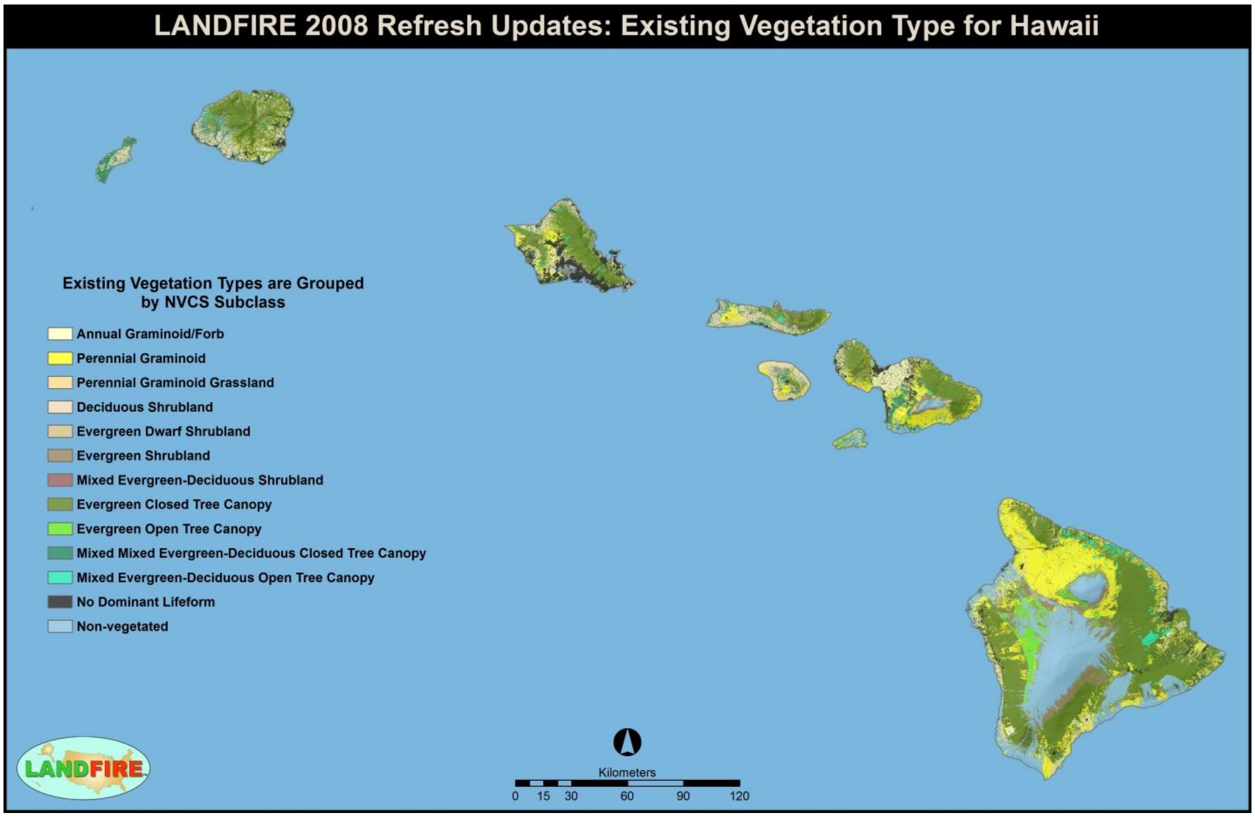

Figure 9 – Map of Existing Vegetation Type layer for the HI GeoArea depicting vegetation changes with disturbances for 1999 - 2008.

Table 10 – Comparison of acreage of Existing Vegetation Types between LF 2001 and LF 2008 in the HI GeoArea.

Table 10. Existing Vegetation Type Comparison			
Existing Vegetation Type	**LF 2001 (acres)**	**LF 2008 (acres)**	**Percent Change**
Hawai'i Lowland Rainforest	498,828	525,694	5.39
Hawai'i Montane Cloud Forest	7,478	7,479	0.01
Hawai'i Montane Rainforest	179,909	179,059	-0.47
Hawai'i Lowland Dry Forest	51,825	47,613	-8.13
Hawai'i Lowland Mesic Forest	149,900	149,609	-0.19
Hawai'i Montane-Subalpine Dry Forest and Woodland	77,898	90,818	16.59
Hawai'i Montane-Subalpine Mesic Forest	185,880	146,948	-20.94
Hawaiian Introduced Wetland Vegetation-Tree	231	232	0.43
Hawaiian Introduced Dry Forest	159,231	160,503	0.80
Hawaiian Introduced Wet-Mesic Forest	315,604	318,376	0.88
Introduced Coastal Wetland Vegetation - Tree	1,449	1,454	0.35
Hawaiian Managed Tree Plantation	47,427	47,856	0.90
Hawai'i Wet Cliff and Ridge Crest Shrubland	26,114	26,124	0.04
Hawai'i Lowland Dry Shrubland	29,488	29,029	-1.56
Hawai'i Lowland Mesic Shrubland	19,341	20,022	3.52
Hawai'i Montane-Subalpine Dry Shrubland	169,300	173,722	2.61
Hawai'i Alpine Dwarf-Shrubland	712	704	-1.12
Hawai'i Dry Cliff	4,697	5,083	8.22
Hawai'i Dry Coastal Strand	5,919	5,947	0.47
Hawai'i Wet-Mesic Coastal Strand	429	429	0.00
Hawai'i Subalpine Mesic Shrubland	3,654	3,575	-2.16
Hawaiian Introduced Wetland Vegetation-Shrub	16	16	0.00
Hawaiian Introduced Deciduous Shrubland	278,851	282,711	1.38
Hawaiian Introduced Evergreen Shrubland	15,477	15,211	-1.72
Introduced Coastal Wetland Vegetation - Shrub	11	11	0.00
Hawai'i Bog	628	628	0.00
Hawai'i Lowland Dry Grassland	2,845	5,745	101.93
Hawai'i Lowland Mesic Grassland	2,970	2,991	0.71
Hawai'i Montane-Subalpine Dry Grassland	3,100	6,615	113.39
Hawai'i Montane-Subalpine Mesic Grassland	761	755	-0.79
Hawaiian Introduced Wetland Vegetation-Herbaceous	979	982	0.31
Hawaiian Introduced Perennial Grassland	698,607	705,822	1.03
Introduced Coastal Wetland Vegetation - Herbaceous	218	220	0.92

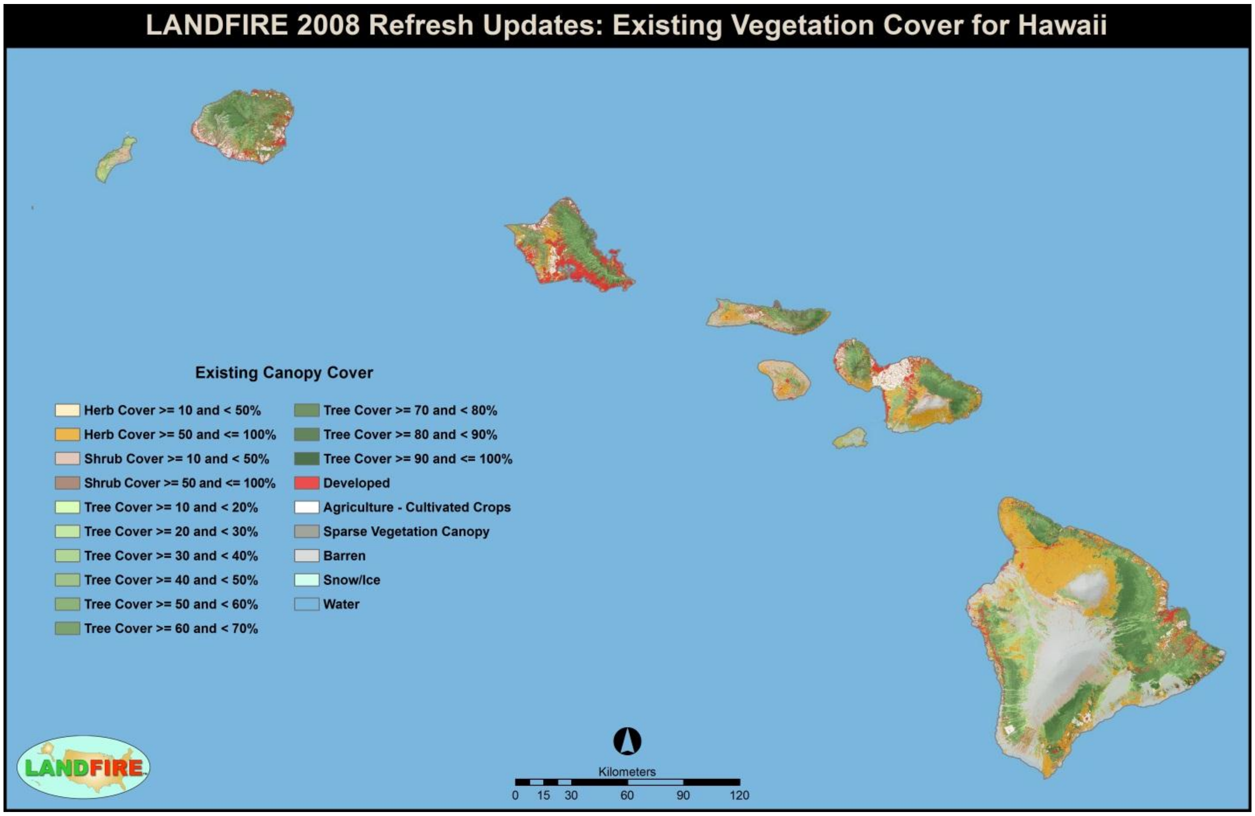

Figure 10 – Map of Existing Vegetation Cover for the HI based upon for vegetation changes from disturbances for 1999 to 2008.

Table 11 – Existing Vegetation Cover: Tree Cover – Comparison between LF Refresh 2001 and 2008.

Table 11. Tree Cover Comparison			
Percent Tree Cover	**LF 2001 (acres)**	**LF 2008 (acres)**	**Percent Change**
>= 10 and < 20	22,959	23,554	0.026
>= 20 and < 30	125,444	125,043	-0.003
>= 30 and < 40	219,796	218,947	-0.004
>= 40 and < 50	220,440	220,064	-0.002
>= 50 and < 60	324,896	325,918	0.003
>= 60 and < 70	379,299	379,833	0.001
>= 70 and < 80	292,157	291,866	-0.001
>= 80 and < 90	80,008	79,759	-0.003
>= 90 and <= 100	10,662	10,662	0.000

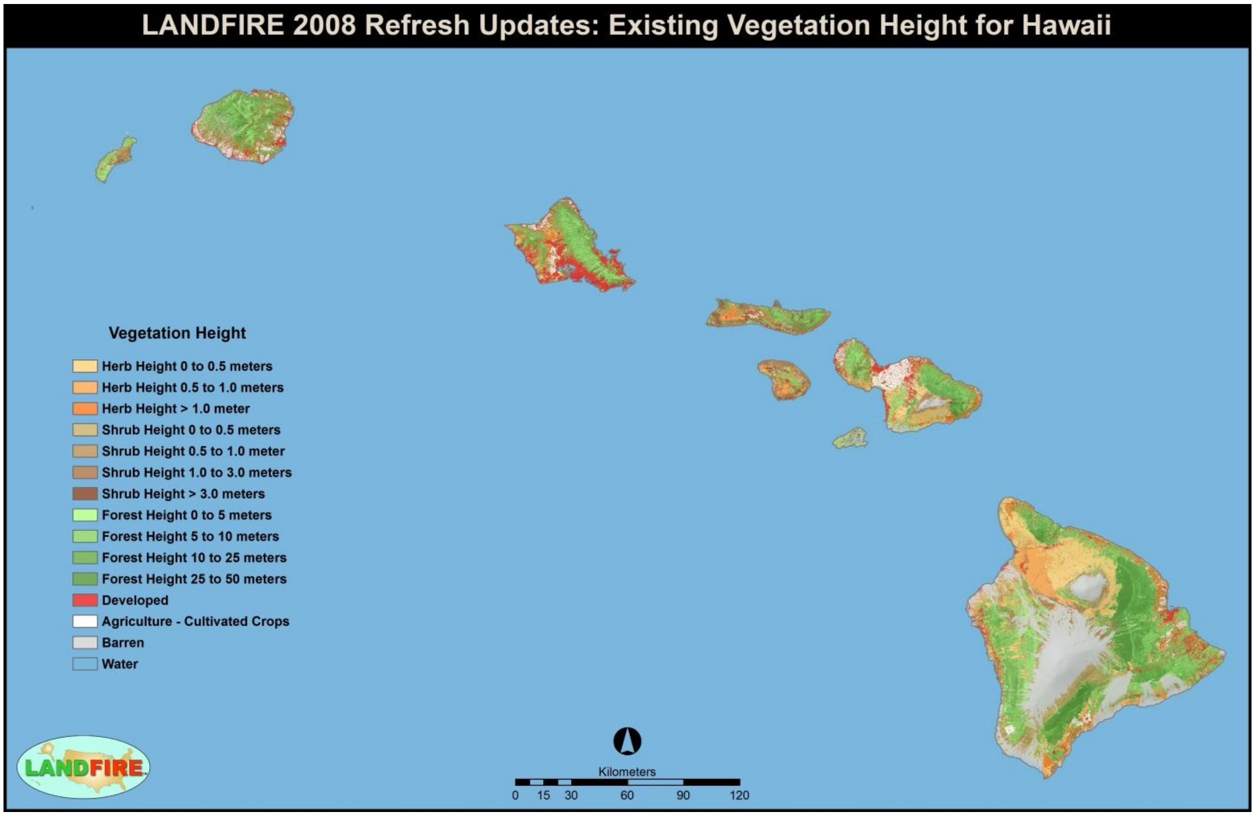

Figure 11 – Map of Existing Vegetation Height for the HI based upon for vegetation changes from disturbances for 1999 to 2008.

Table 12 – Existing Vegetation Height: Tree Height – Comparison between LF Refresh 2001 and 2008.

Table 12. Tree Height Comparison			
Height (m)	**LF 2001 (acres)**	**LF 2008 (acres)**	**Percent Change**
0 to 5	172,652	171,802	-0.005
5 to 10	757,848	757,605	0.000
10 to 25	429,896	431,000	0.003
25 to 50	315,265	315,237	0.000

2.6 Fire Behavior

2.6.1 Product Description

The LF fuels data describe the composition and characteristics of both surface and canopy fuel. Geospatial products include fire behavior fuel models (FBFM13 [Anderson 1982], FBFM40 [Scott and Burgan 2005], Forest Canopy Bulk Density (CBD), Forest Canopy Base Height (CBH), Forest Canopy Cover (CC), and Forest Canopy Height (CH). The landscape file (LCP) is the data format required for many fire behavior and effects models and was provided as well. These data can be implemented within models to forecast wildland fire behavior and effects that are useful for strategic fuel treatment prioritization and for tactical assessments during firefighting operations.

2.6.2 LF 2001 Enhancements to Fire Behavior Products

LF FBFM layers were calibrated as part of the LF 2001 Refresh effort. FBFM assignment rules were evaluated and modified based on local expert input and experience.

2.6.2a Enhanced Surface Fuel

The FBFM40/13 fuel model grids for LF National were based on input provided by regional fuel specialists and the LF fuel team. Surface fuel models were dependent upon the type of vegetation described in the EVT layer, the amount of cover in the overstory of the vegetation from EVC, and the height of the vegetation expressed by EVH. Fuel model assignments were given break points of EVC and EVH for each EVT to determine the fuel model. For instance, in a forested EVT in an open condition, a grass or shrub model would be used in the low cover rule set to describe the surface fuel. As the stand closed in the higher EVC classes, a timber understory or timber litter model would often be used in a subsequent rule set. The newly calibrated surface fuel rule set was applied to the LF2001 EVT, EVC, and EVH data to derive the LF2001 FBFM products. Figure 12 depicts the LF 2001 FBFM40 fuel models for Hawai'i.

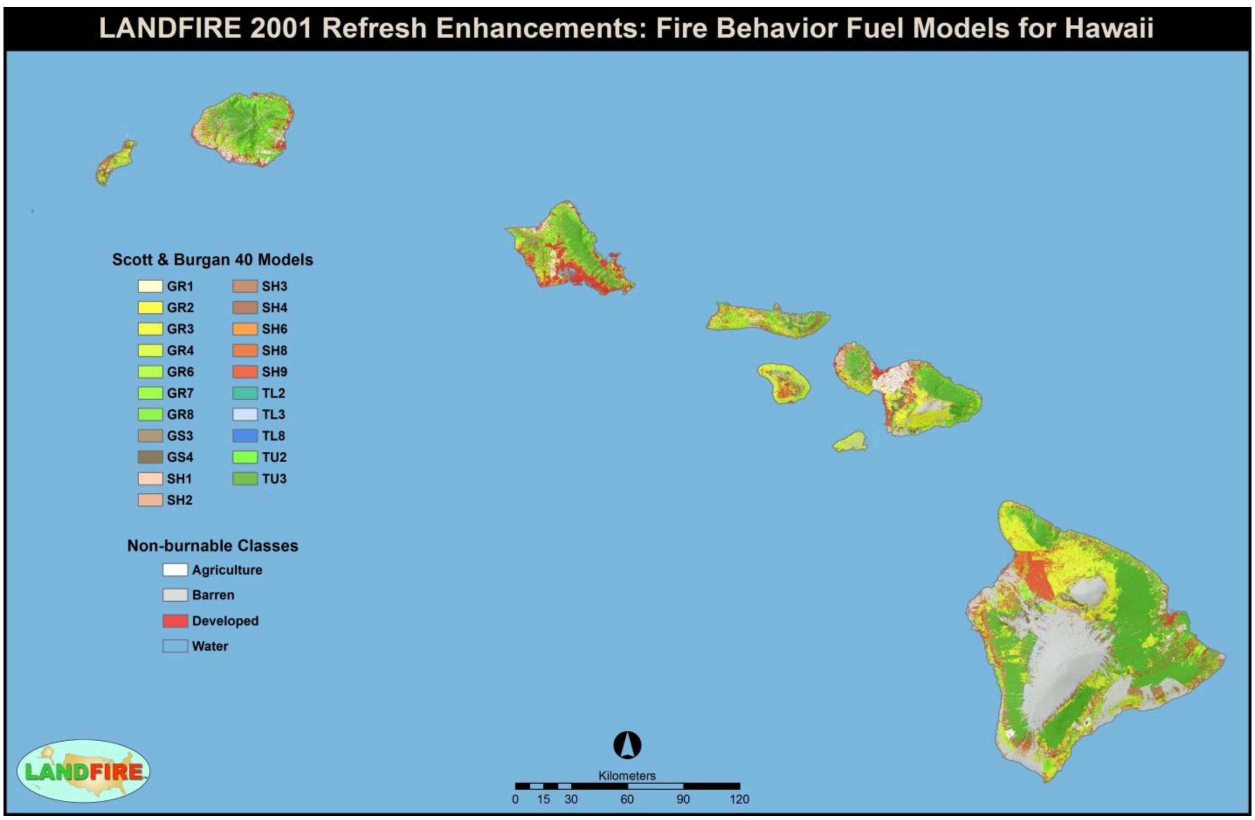

Figure 12 – LF 2001 Fire Behavior Fuel Model 40 (Scott and Burgan, 2005) for the HI GeoArea.

2.6.2b Enhanced Canopy Fuel

The CC and CH layers were directly affected by the changes in EVC and EVH, and the grids for CBH and CBD were calculated from the new values in CC and CH. The CBH data layer was developed through exploratory analysis of the LF plot data and statistically analyzed to search for relationships between the plot level variables and CBH. Unfortunately, no such relationship could be gleaned between these variables. It was determined that CBH would be represented through an averaging method based on combinations of EVT and coarser groupings of EVT with EVH and EVC categories.

The CBD data layer was also developed through exploratory analysis of the LF plot data. The entire LF plot data compiled for the western United States were statistically analyzed to search for relationships between the plot level variables and CBD. A General Linear Model (GLM) was developed that expresses the relationship between CBD and CC, CH, and EVT (Reeves et al. 2009).

2.6.3 LF 2008 Updates to Fire Behavior Products

The LF 2008 update process was an attempt to model the vegetation and fuel characteristics depicted in the circa 2001 imagery (LF National) to the more current period of 2008. The main effort of this process was to incorporate vegetation growth and disturbance over the time period. Regarding fuel characteristics, the changes in surface fuel models (FBFM40, FBFM13, and FCCS) and canopy characteristics in the disturbed areas were incorporated according to expert opinion.

2.6.3a Updates to Surface Fuel

The FBFM 40/13, FCCS, and canopy fuel were transitioned from their original assignment in LF 2001 based on type, intensity, and the time since disturbance. Vegetation outside of disturbed areas maintained the same surface fuel model unless there was some change in the EVT. Vegetation was transitioned using the process explained in Section 2.5.3.

Time since disturbance was separated into two categories, or time steps, for surface fuel: 0-3 years post disturbance and 4-10 years. For each time step, one FBFM 40/13 and FCCS was assigned to represent the surface fuel characteristic for the period. Generally, the first step was visualized as a full growing season and the second step was 7 years post disturbance. The transitions of surface fuel models in disturbed areas were assigned by the LF fuel team and then sent to regional experts for review and editing. The resulting FBFM40 fuel models are represented in Figure 13.

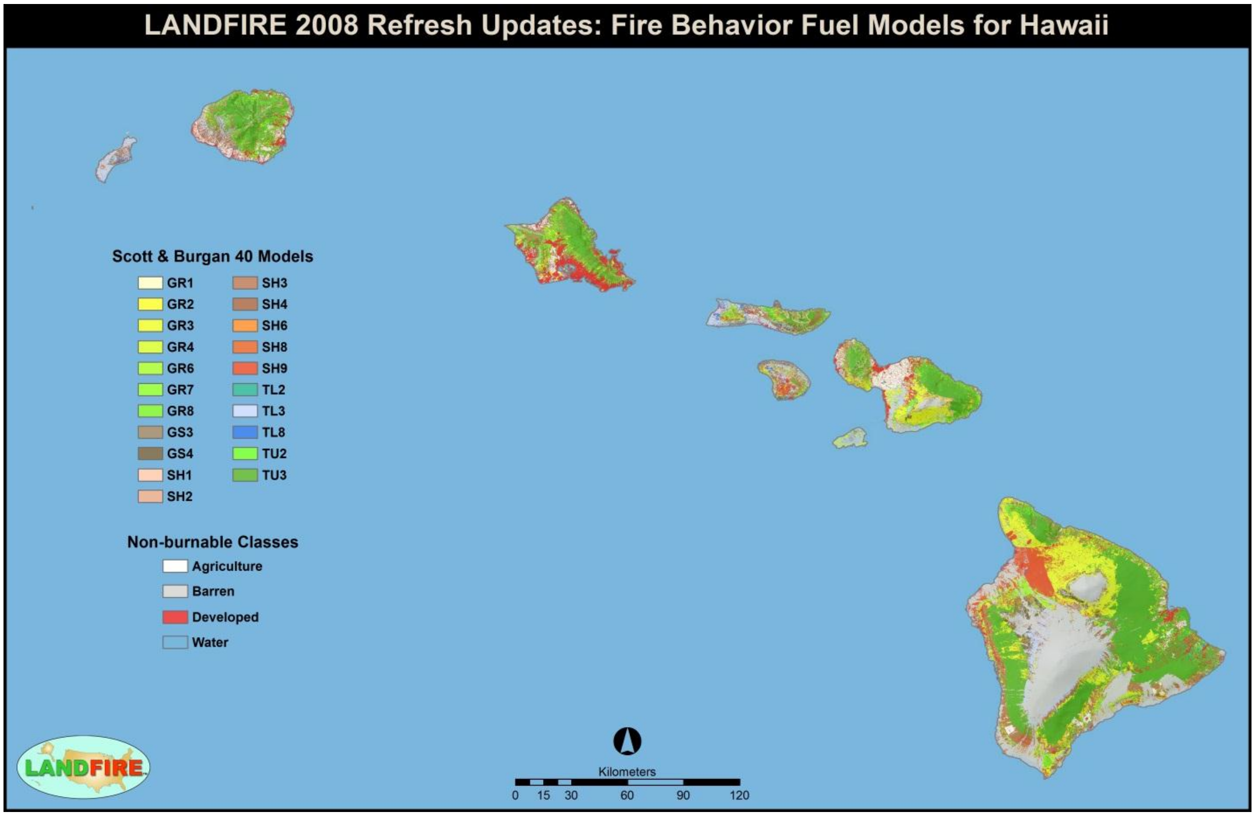

Figure 13 – LF 2008 Fire Behavior Fuel Model 40 (Scott and Burgan, 2005) for the HI GeoArea.

2.6.3b Updates to Canopy Fuel

The changes in canopy attributes and the growth in non-disturbed areas were modified according to local expert opinion. Values for CC, CH, and CBD were recalculated using the 2008 EVC, EVH and EVT. The coefficients of change in the CBH attributes were applied to the usual calculation of CBH based on the type, severity, and time since disturbance. Time since disturbance was implemented in three time steps for canopy fuel; 1) immediately after the disturbance, 2) 3-5 years post disturbance and 3) 7-10 years post disturbance. For each time step, a CBD value was calculated using the GLM and the updated LF 2008 EVT, EVC and EVH data layers.

2.7 Fire Effects

2.7.1 Product Description

The LF fire effects data layers describe the composition and characteristics of both surface fuel loadings and canopy fuel loadings, which are represented in Hawai'i by the Fuel Characterization Classification System (FCCS) fuelbed models (Ottmar et al. 2007). FCCS data may be used within fire behavior models to forecast the effects of wildland fire for strategic fuel treatment prioritization and tactical assessment of fire behavior.

FCCS fuelbeds were developed by the Fire and Environmental Applications Team (FERA) at the USFS Pacific Wildland Fire Sciences Laboratory using data from the following sources: regional workshops, published literature, USFS photo series, general technical reports, research papers, other government literature, large databases, masters and doctoral theses, white papers, field data, and other unpublished data, and expert opinion. FCCS defines a fuelbed as the inherent physical characteristics of fuel that contribute to fire behavior and effects (Riccardi et al. 2007). This is a set of measured or averaged physical fuel characteristics of a relatively uniform unit on the landscape that represents a distinct fire environment. An FCCS fuelbed can represent any scale or precision of interest. In FCCS, fuelbeds represent realistic fuel conditions and can accommodate a wide range of fuel characteristics in six horizontal fuel layers called strata (Ottmar et al. 2007). The strata include canopy, shrub, non-woody vegetation, woody fuel, litter/lichen/moss, and ground fuel. Each stratum was further divided into 16 categories and 20 subcategories to represent the complexity of wildland and managed fuel types in the United States.

2.7.2 LF 2001 Enhancements to Fire Effects Products

2.7.2a Enhancements to the Fuel Characterization Classification System fuelbeds

The FCCS fuelbeds mapping relied almost entirely on the LF EVT layer. A crosswalk was constructed between LF EVT and FCCS fuelbed classes. Where multiple FCCS fuelbeds could exist within a single EVT class, EVC and EVH were used to further refine the crosswalk. The final crosswalk was converted into a rule set and applied to the EVT, EVC, and EVH data to produce the final FCCS layer.

2.7.3 LF 2008 Updates to Fire Effects Products

2.7.3a Updates to Fuel Characterization Classification System Fuelbeds

The same crosswalk and mapping rules that were used for LF 2001 were used for LF 2008, which included rules for disturbed pixels that took into account disturbance type, severity, and time since disturbance.

2.8 Fire Regime Products

2.8.1 Product Description

Broad-scale alterations of historical fire regimes and vegetation conditions have occurred in many landscapes in the U.S. through the combined influence of land management practices, fire exclusion, ungulate herbivory, insect and disease outbreaks, climate change, and invasion of non-native plant species. The LF program produced maps of historical fire regimes and historical vegetation conditions using the Vegetation Dynamics Development Tool (VDDT; ESSA Technologies Ltd., 2007), which is a state and transition model. The LF Program also produced maps of current vegetation and measurements of current vegetation departure from simulated historical reference conditions. The LF 2001/2008 update was accomplished by using the FRCC Mapping Tool (FRCCMT; Jones and Tirmenstein, 2012) to perform the FRCC calculations as defined in the Interagency Fire Regime Condition Class Guidebook (Barrett et al. 2010). FRCCMT relied on the use of a variety of spatial inputs, including the BpS and SCLASS layers and LF 2001 Fire Regime Landscape layers.

SCLASS categorizes current vegetation composition and structure in up to five successional states defined for each LF BpS model. Two additional categories define uncharacteristic vegetation components, such as exotic species, that were not found within the compositional or structural variability of successional states defined for each BpS model. These succession classes were similar in concept to those defined in the FRCC Guidebook. The FRCC data layer categorizes departure between current vegetation conditions and reference vegetation conditions according to the methods outlined in the FRCC Guidebook. This departure index is represented using a 0 to 100 percent scale, with 100 representing maximum departure. The departure index was then classified into three condition classes. It is important to note that the LF FRCC approach differs from that outlined in the FRCC Guidebook as follows: LF FRCC was based on departure of current vegetation conditions from reference vegetation conditions only, whereas the Guidebook approach also includes departure of current fire regimes from those of the reference period. As such, LF has made a transition from calling these products FRCC data products to Vegetation Condition Class (VCC). Similarly, the FRCC departure has been changed to Vegetation Departure Index (VDEP).

2.8.2 LF 2001 Enhancements to Fire Regime Products

2.8.2a Enhancements to Summary Units

The LF 2001 fire regime product was developed to provide a spatial summary unit for processing within each GeoArea using the FRCCMT. It is one of five inputs used to analyze departure with FRCCMT, allowing for scale-appropriate analyses for each stratum according to its associated FRG (Barrett et al. 2010). The outputs from FRCCMT differ as the size and/or shape of the landscape being analyzed changes. It is therefore important to select appropriately sized landscapes when using FRCCMT. For Hawai'i, all the islands were analyzed together as one landscape.

2.8.2b Enhancements to Succession Classes

The SCLASS layer was created by linking the BpS layer with the Refresh Model Tracker (RMT) data and assigning the RMT attribute. This geospatial product displays a reasonable approximation of SCLASS, documented in the RMT. The current successional classes and their historical reference conditions were compared to assess departure of vegetation characteristics; this departure can be quantified using methods such as FRCC. SCLASS rules for each BpS were designed to meet the following criteria: 1) represent the existing locations of a BpS SCLASS on the landscape and 2) meet the input requirements for the FRCCMT. User feedback had identified two primary issues with the LF National BpS SCLASS rules.

1. Many of the rules in the RMT database conflicted due to overlapping cover and height ranges.
2. Some life-forms that were mapped within a given BpS should not have been included based on the BpS model description for the SCLASS. These cases are referred to as "life-form mismatches."

BpS models and SCLASS rules were evaluated against the BpS model descriptions and adjusted to accurately reflect the intent of the model. In some cases the cover and height values either matched or remained similar to the original model. In other cases the cover and height values were adjusted considerably. The SCLASS rule revision process eliminated overlap between cover and height ranges of the SCLASS rules for a given BpS. Overlapping rules were edited so that only one rule applied to each pixel. In some cases correcting the overlapping values resulted in cover or height values that were one or more categories above or below the original model.

In the case of life-form mismatches, the life-forms that were mapped as part of the BpS but not allowed by the SCLASS rules were reviewed and reassigned to an uncharacteristic class and the probable source of the error was documented. The resulting updates to SCLASS are symbolized in Figure 14.

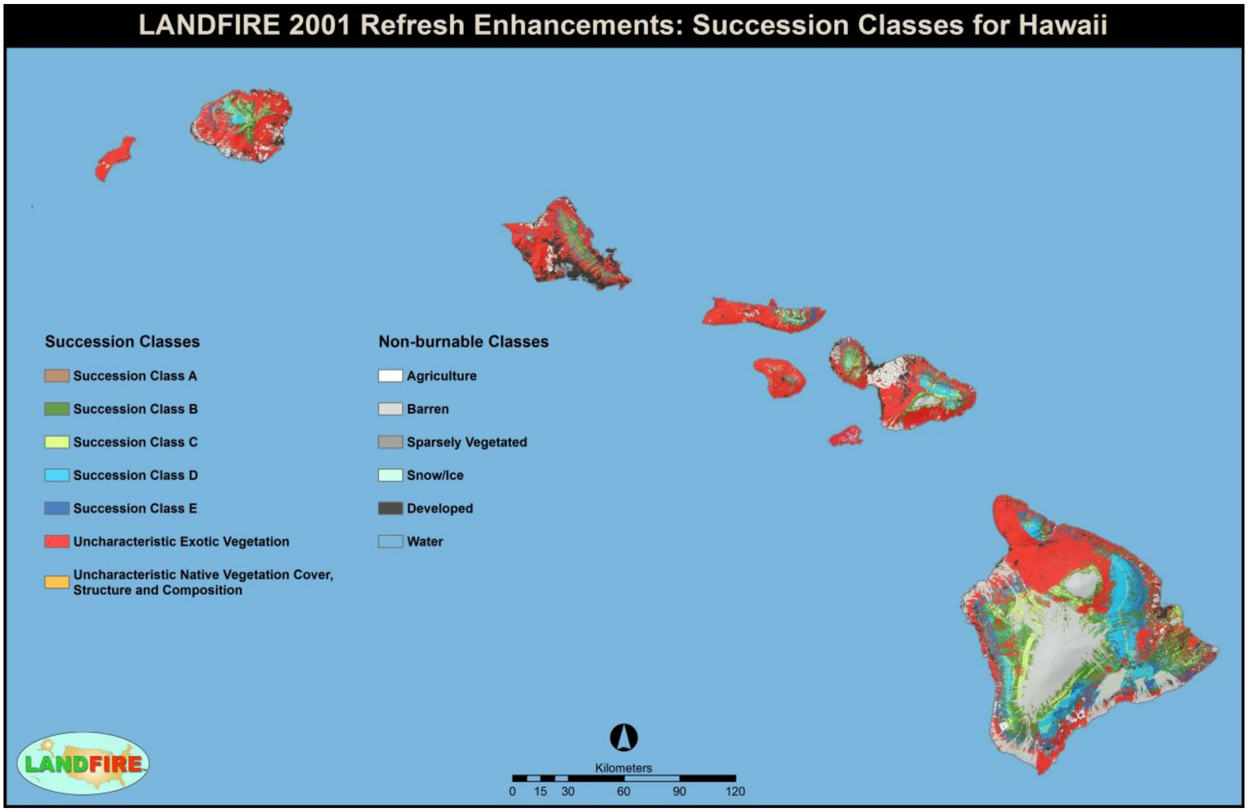

Figure 14 – Map of LF 2001 enhancements of the Succession Class layer for the HI GeoArea.

2.8.2c Enhancements to Vegetation Departure

Unlike previous versions of LF data, reference conditions of percent composition for each of the characteristic SCLASS were derived from modeling workshops with the intent to approximate the definitions outlined in the FRCC Guidebook. Modelers used the VDDT, which uses state and transition landscape modeling to simulate the effect of disturbance and management actions on a landscape over time. The results are stored in the LF RMT.

The current conditions were derived from the corresponding version of the LF SCLASS data layer. The areas currently mapped to agriculture, urban, water, barren, or sparsely vegetated BpS units were not included in the FRCC calculation; thus, FRCC is based entirely on the remaining area of each BpS unit that is occupied by valid SCLASS. To calculate the Stratum Vegetation Departure, FRCCMT used the LF Refresh BpS layer to stratify the LF Refresh SCLASS layer. Once the SCLASS layer was stratified by BpS, FRCCMT was able to calculate the Current Percent Composition for each SCLASS within each BpS.

FRCCMT then used the Current Percent Composition for each of the SCLASS within a BpS along with the corresponding Reference Percent Compositions for that BpS from the Reference Condition Table to calculate the Stratum Vegetation Departure, which is described above. The Stratum Vegetation Departure grid was calculated by comparing the Reference Percent Composition of each SCLASS to the Current Percent Composition, summing the smaller of the two for each of the SCLASS to determine the

Stratum Similarity. This value was then subtracted from 100 to determine the Stratum Vegetation Departure. The VCC grid (Figure 15) is a 3-category classification of the Stratum Vegetation Departure based on the following thresholds:

1. VCC I: Stratum Vegetation Departure of 0 to 33
2. VCC II: Stratum Vegetation Departure of 34 to 66
3. VCC III: Stratum Vegetation Departure of 67 to 100

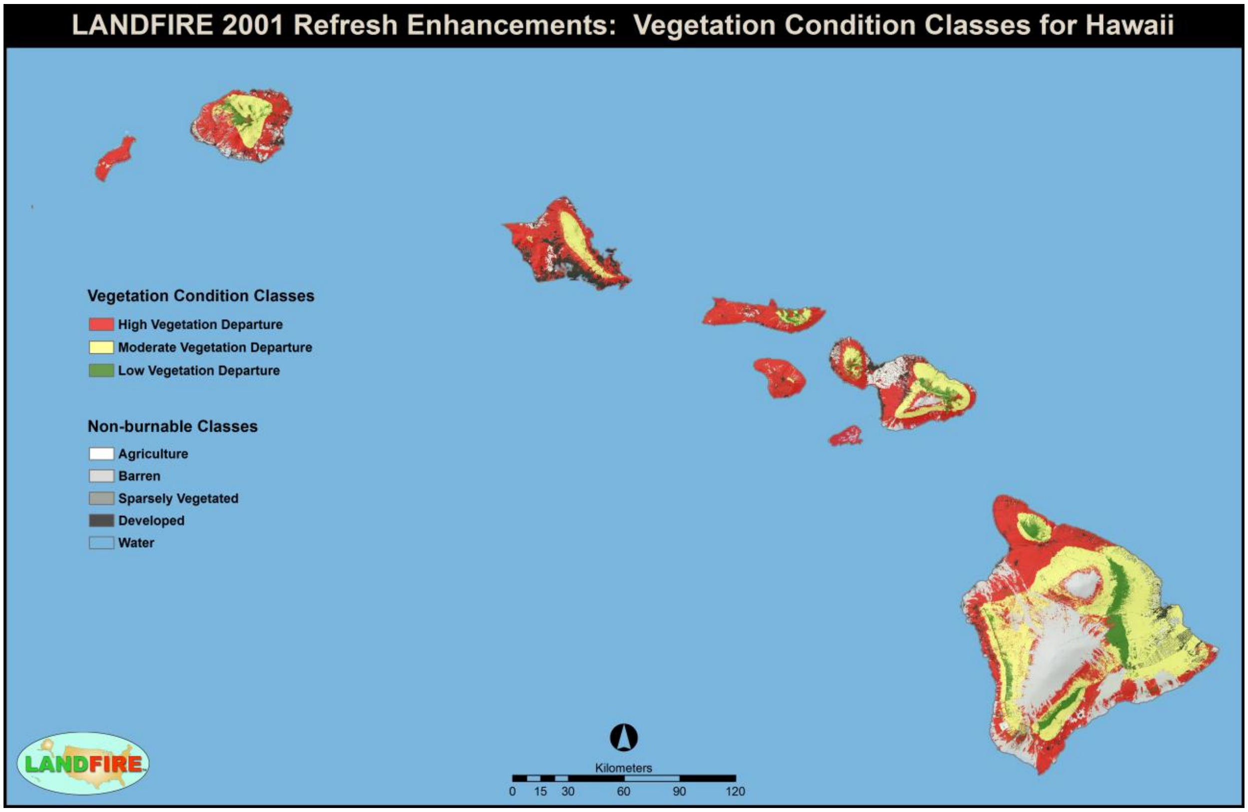

Figure 15 – Map of Vegetation Condition Class for the HI GeoArea from LF 2001 enhancements.

2.8.3 LF 2008 Updates to Fire Regime Products

2.8.3a Updates to Succession Classes

The same SCLASS mapping rules that were used for LF 2001 were used for LF 2008 (Figure 16). Mapping rules were applied to LF 2008 EVT, EVC, and EVH layers to map the LF 2008 SCLASS layer.

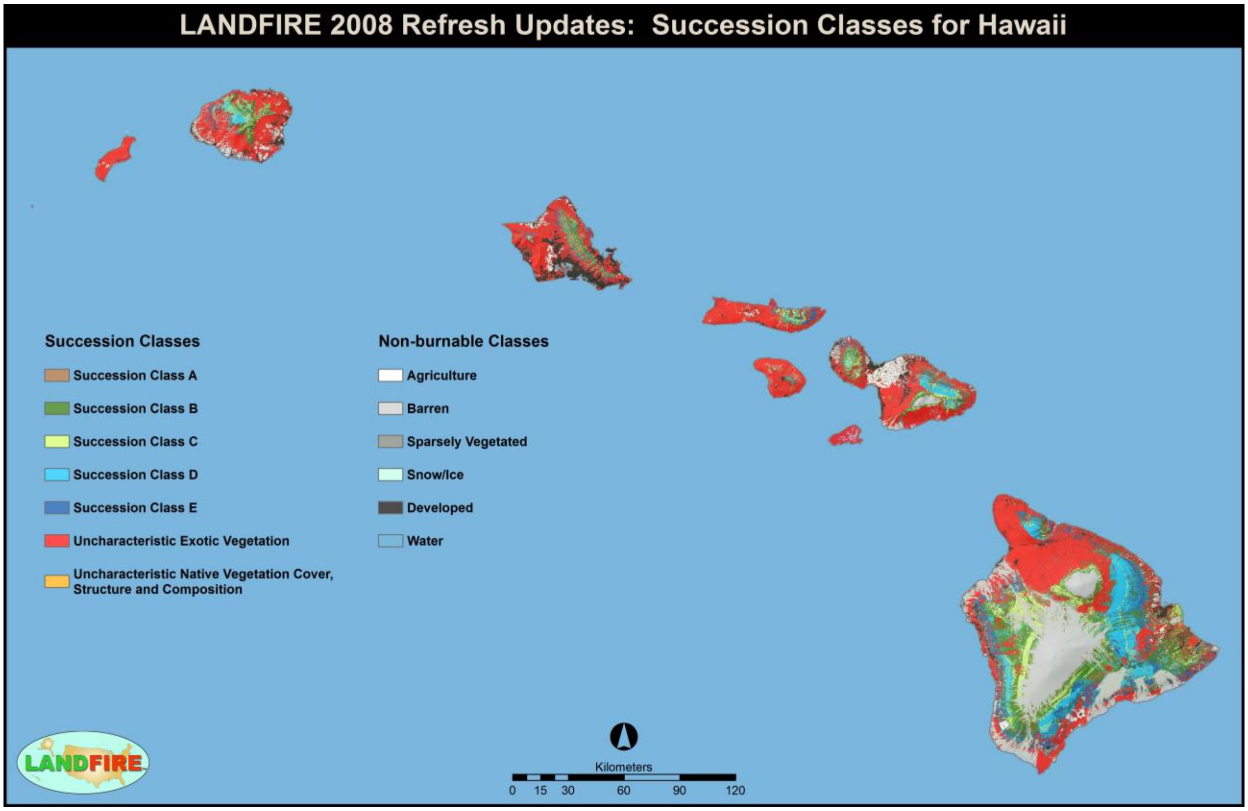

Figure 16 – Map of LF 2008 updates of the Succession Class layer for the HI GeoArea.

2.8.3b Updates to Vegetation Departure

FRCCMT was used to calculate the current percent composition for each of the LF 2008 SCLASS within a BpS along with the corresponding reference percent compositions for that BpS from a reference condition table to calculate the LF 2008 stratum vegetation departure. The LF 2008 VCC grid depicted in Figure 17 was derived from a 3-category classification of the stratum vegetation departure as defined in Section 2.8.2c.

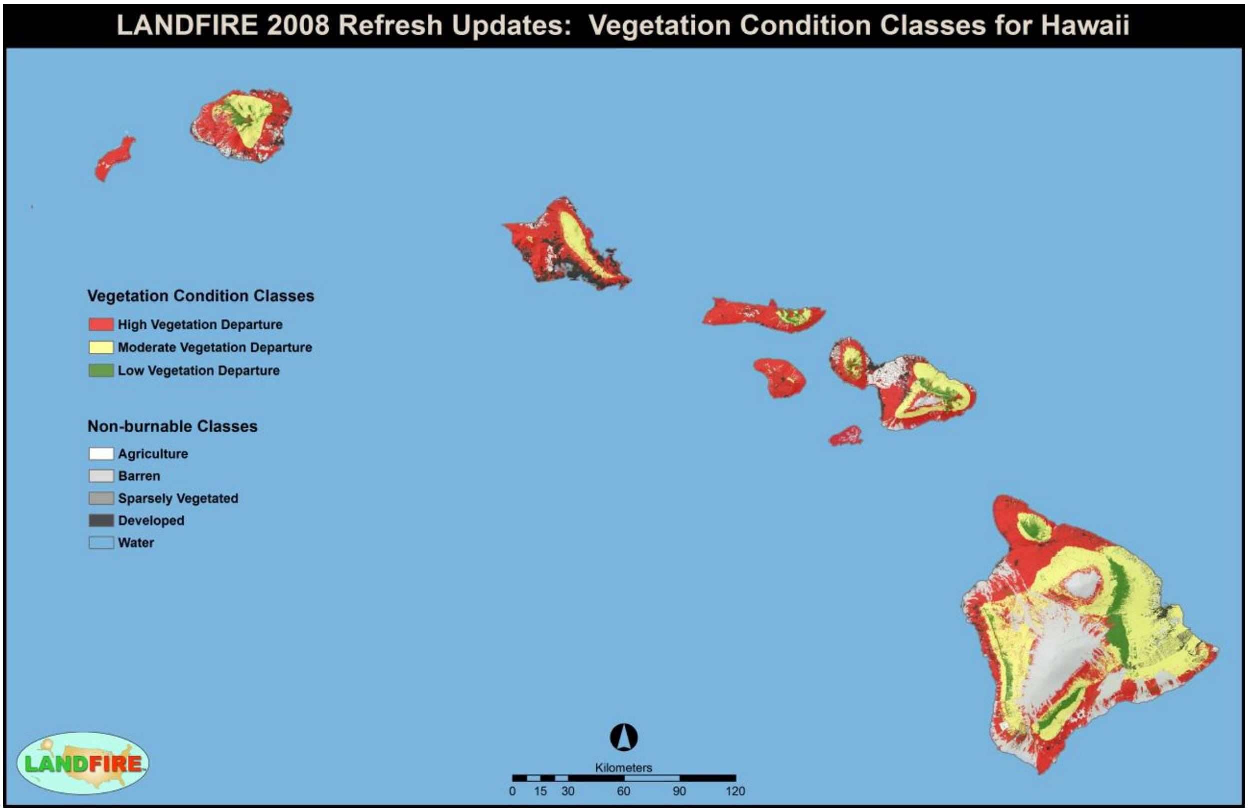

Figure 17 – Map of Vegetation Condition Class for the HI GeoArea from LF 2008 updates.

3.0 FARSITE Comparison of LANDFIRE Fuel

This section describes the results of an evaluation of one or more of the LF fuel datasets when compared to a historical fire. The FARSITE program was used to model fire behavior using different LF fuel data sets. The output of each model run was compared with the final perimeter of an actual wildland fire to evaluate spread rates, spread distances, and other environmental conditions to determine the efficacy of each LF fuel dataset. Fires were selected from one of several sources, either the MTBS Fire Occurrence Database for each of the representative geographic areas, National Interagency Fire Center, or information provided by fire personnel related to the fire. The LF data sets that were used throughout this process were FBFM13 and FBFM40, CC, CH, CBH, and CBD from LF 2001, and LF 2008. Slope, elevation, and aspect were also included as inputs. Below is an example of a comparison between LF data sets and the final perimeters of an actual wildland fire.

It is noted that a major limitation of the LANDFIRE fuel data in Hawai'i is the lack of appropriate surface fuel models to represent many of the tropical vegetation types, especially exotic grasses. Some of the exotic grasses burn at very high live fuel moisture values; a condition that is not well represented in either the FBFM13 or FBFM 40 standard fuel model sets. LANDFIRE has been open to the idea of exploring custom fuel models in specialized cases such as this; however, a lack of consensus among local scientists on the most appropriate custom fuel models to use in Hawai'i has prevented LANDFIRE from implementing new models at this time. This issue will continue to be discussed and re-visited in future updates.

3.1 Napau Fire, 2011

The Napau Fire occurred on the Island of Hawai'i also known as the Big Island in mid-March of 2011 just southeast of Kilauea Volcano near the coast. The fire was managed between natural barriers, so little was done in terms of traditional fire suppression actions. A lava flow was the ignition source and the first known perimeter was from March 14th with a final fire size of just over 1,700 acres on March 23rd. Energy Release Component of the National Fire Danger Rating System was well above average and approached setting records for these dates, but was below the overall 90th percentile, compared to previous years. High wind speeds had the most dominate effect on the fire activity.

The vegetation of the fire site is described in the LF data as principally, Hawaiʻi Lowland Mesic Forest (EVT 2814), which comprises 90% of the fire area. The other 10% is fairly equally divided between, Hawaiʻi Lowland Dry Forest (EVT 2813) and Introduced Perennial Grasslands (EVT 2848).

3.1.1 Inputs

Weather, wind, and fuel moisture data used in the fire simulations were from Hilina Pali and Kealakomo Remote Automated Weather Station (RAWS) located in close proximity to the fire site. Wind speeds (10 minute average) at the 20 ft level ranged from 15 to 28 mph and gusts were recorded into the mid 30 mph range with directions from the north and northeast. The hourly mid-point value between 10 minute average and maximum gust wind speed and wind direction values were used in the simulation. Beginning dead and live fuel moisture values were derived from the Hilina Pali site.

The LF 2001 FBFM40 layer for the fire area is composed mainly of Shrub (SH) 3 (143), 90% of the fire area is in the fuel model class that corresponds to EVT 2814. The remaining 10% are mostly grass models Grass (GR) 3 (103) and GR4 (104) with some areas of Timber-understory (TU) 3 (163) and TU2 (162). LF 2001 and LF2008 only differ in surface fuel models (FBFM40) within EVT 2814 where high severity fire disturbance occurred in a 2003 event, where these differences occur, the FBFM40 transitions from a SH3, GR3, and GR4 to GR1 (101).

CBH in LF 2001 is 5 m throughout the SH3 fuel model and is the same in LF 2008. In LF 2008 the change in CBH occurs where the high severity in the previous disturbance causes the FBFM40 to go to GR1 with no canopy attributes.

Perimeter data for March 14th through the 18th exist for this fire along with the final perimeter of the 23rd. This assessment primarily focused on the fire spread on the 16th (Figure 18). The thermal infrared (IR) map from the previous burn period on the 15th will be used as the ignition source. An 8 hour burn period from 10:00 am to 6:00 pm was used to simulate fire spread. The burn period length was derived from the hours of low fuel moistures and high wind speeds in the RAWS data. Crown fire activity was set to the Scott and Reinhardt (2001) method and spotting was enabled at 1.0%. A fuel moisture and environmental conditioning period was used from March 12th and the simulation began on the 16th.

3.1.2 Results

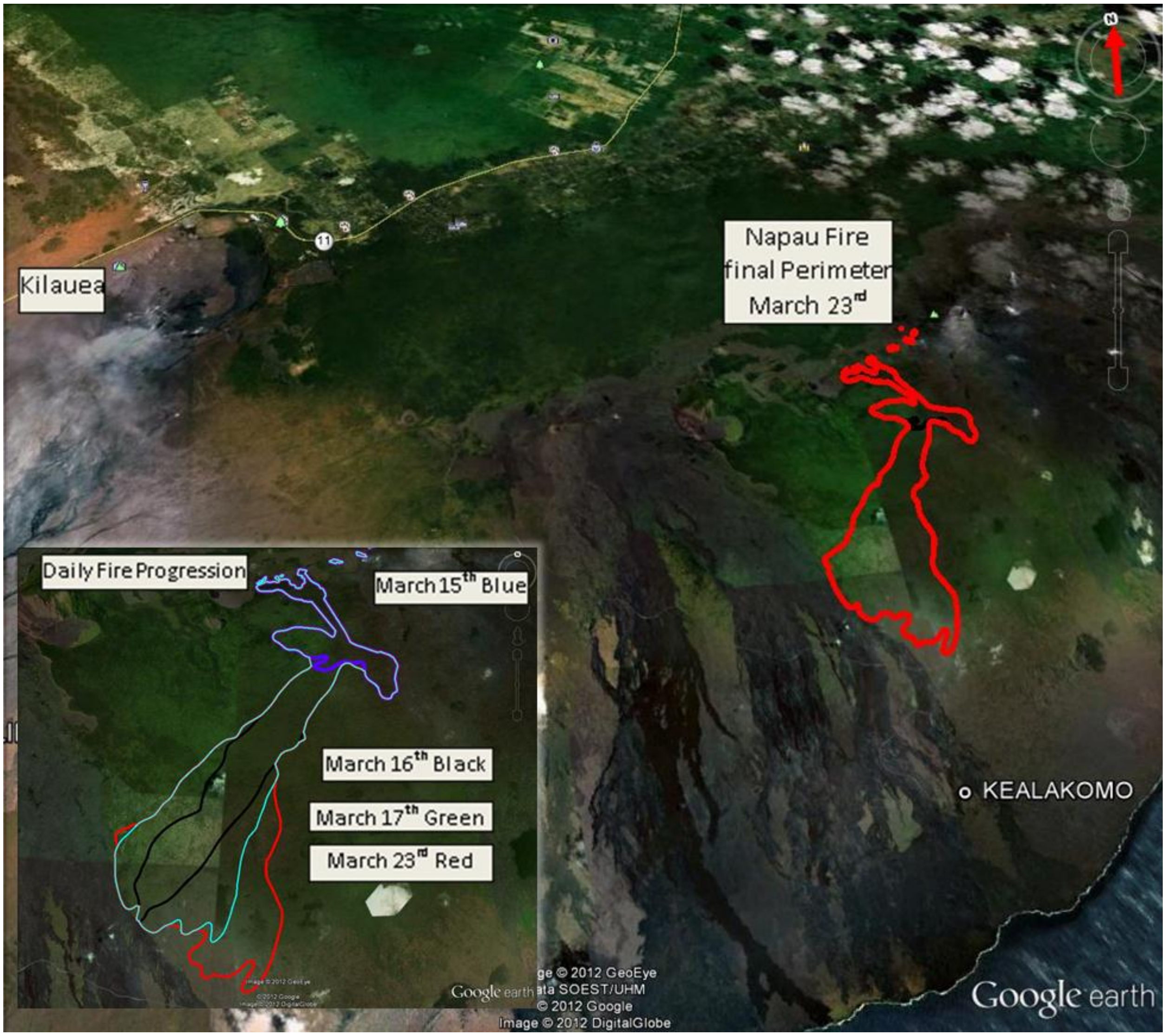

Figure 18 - Overview of Papau Fire March 2011. The fire extended nearly 4 miles in length depicted by the black line.

Several attempts were made to model the LF 2001 landscape file to simulate the fire spread of March 16th. The first, displayed in Figure 19, is with the use of base information such as: standard downloaded fuels characteristics in the landscape file, standard 10 minute average 20 ft wind speed values, and standard fuel moisture values from the RAWS.

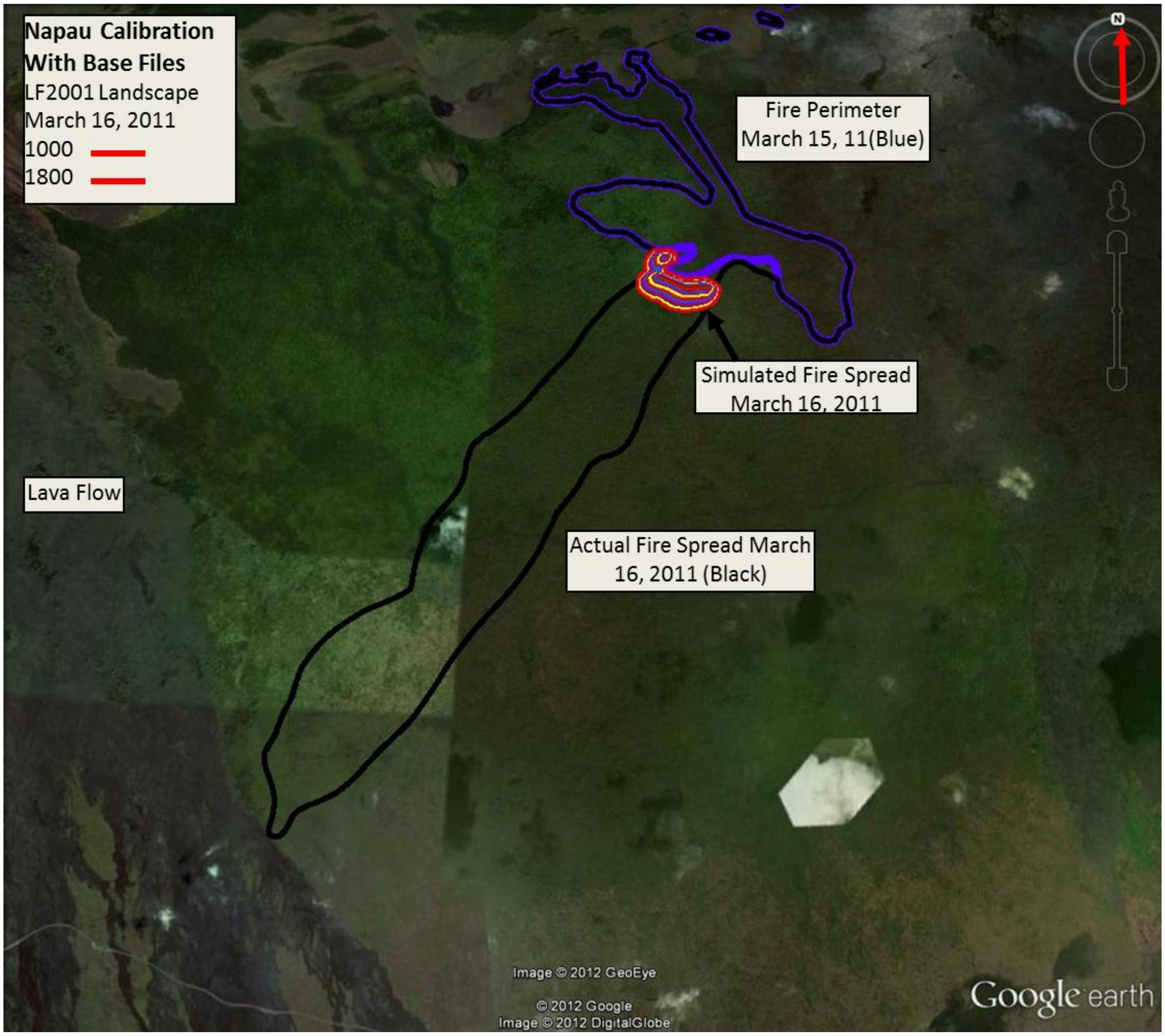

Figure 19 - LF Landscape Simulation for the Napau Fire 2011. The fire extended nearly 4 miles in length depicted by the black line.

Under base conditions the SH3 fuel model will not allow the simulated fire to spread close to the actual extent of March 16th. Several variables in the simulation were changed systematically to allow for better simulated fire spread. The first variable considered and changed was wind speed. In subsequent assessments the mid-point between 10 minute average and maximum gust values for wind speed were used with little increase in simulated fire extent. The next variables considered for change were fuel characteristics of CBH (within the SH3 fuel model) and a change of the FBFM40 SH3 to another shrub model. The first assessment of change within fuel characteristics was performed by reducing CBH by half from 5 m to 2.5 m and using median point winds. These results were marginal, as can be seen in Figure 20, this resulted in the reduction of CBH to < 1m and using median wind speeds.

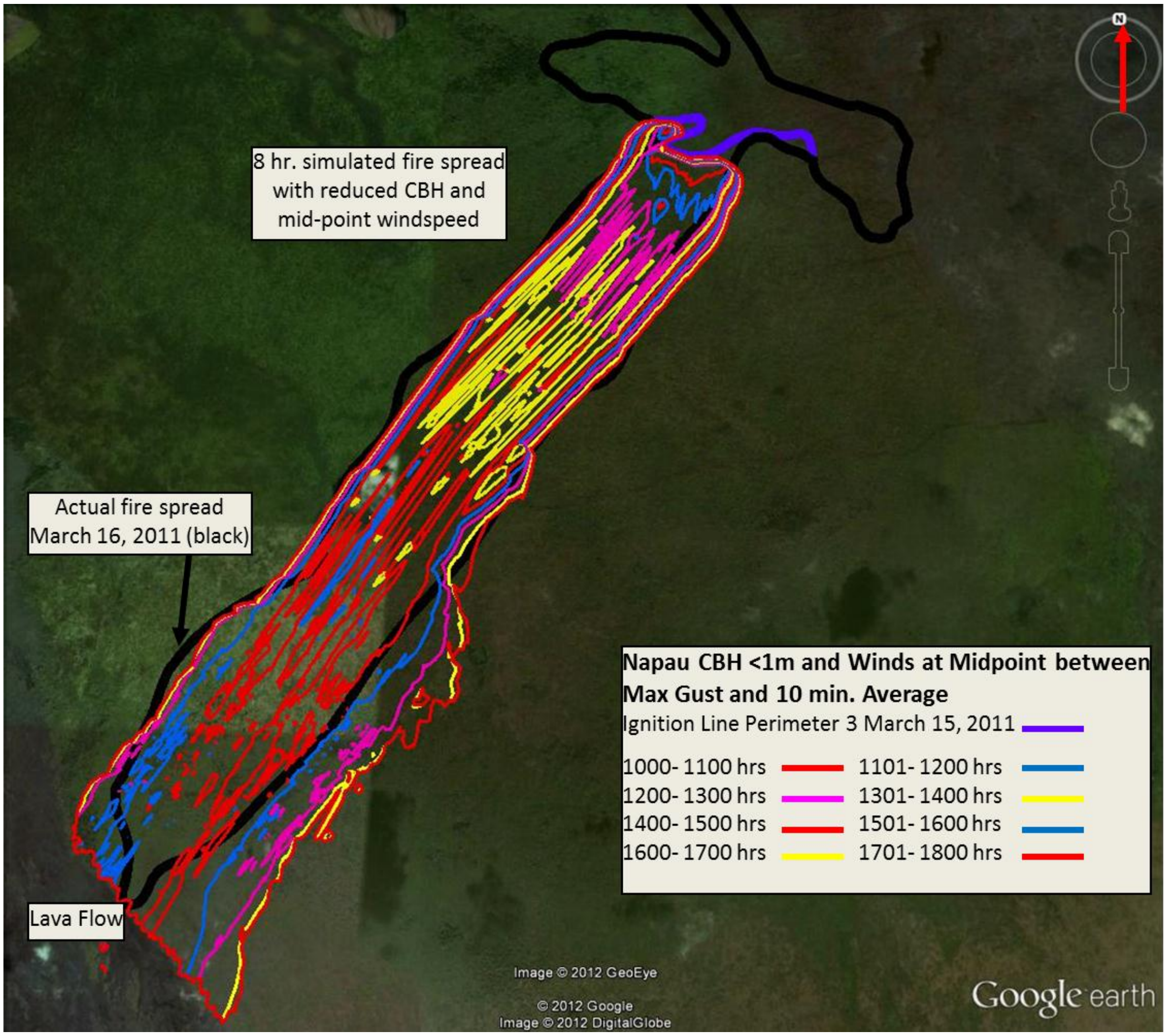

Figure 20 - LF 2001 Simulation with Reduced CBH and Median (10 min, Average and Maximum Gust) Wind Speeds. The fire extended nearly 4 miles in length depicted by the black line.

The understory of the Hawaiʻi Lowland Mesic Forest in the fire area was described by the NPS resource manager as being Uluhe, which is dense matted fern vegetation that clambers over the ground and sparse shrubs, and climbs into trees, creating a laddered fuel bed. The gap between the surface fuels and the lower canopy is not represented by the CBH in the LF 2001 landscape file. The description goes on to discuss fire behavior traits of Uluhe sites: "Uluhe and sword fern appear to be "go/no go" fuels. They carried fire only under very windy conditions when humidity's were relatively low for their environment (50-60%), after a drying trend of one to several days. Protracted dry periods were not necessary for fire spread. Although the wind threshold for fire spread was not quantified, when these conditions were reached, fire tended to spread rapidly as wind-driven head fires" (former Resource Manager Tim Tunison in an undated document). For the LF 2001 landscape file the "go threshold" is CBH < 1m and 10 minute average winds at 20 ft of 27 to 31 mph (mid-point between 10 minute average and maximum gust).

Another approach considered was to change the FBFM40 model from SH3 to SH8 (148), which is a heavier shrub load. Although the SH8 landscape file simulates a substantial increase in fire spread with 10 minute average wind speed, the best results from this approach came from the combination of SH8 with mid-point wind speed values (Figure 21).

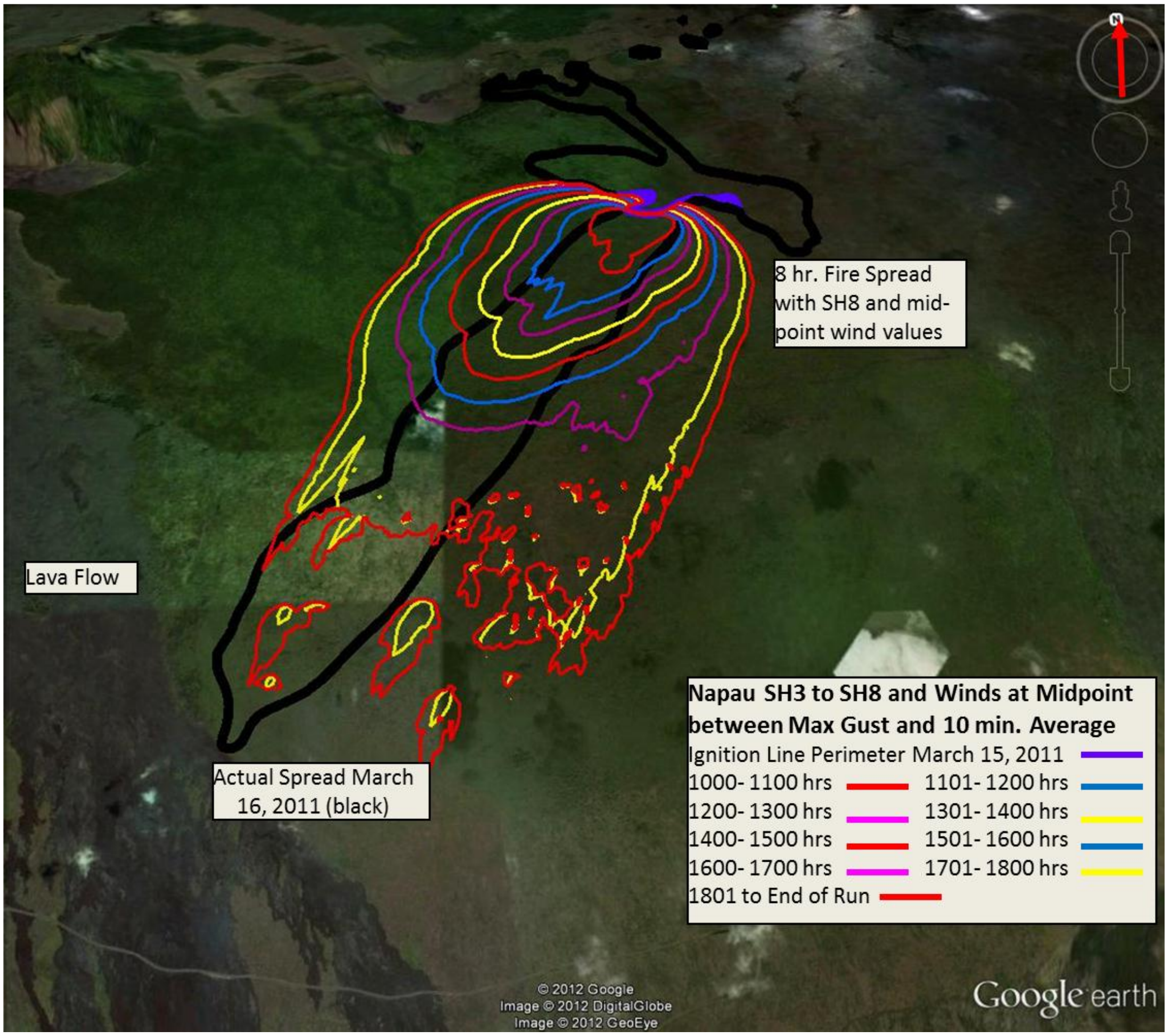

Figure 21 - Simulation of Napau Fire on LF 2001 Landscape File with Alternative Surface fuel Model. The fire extended nearly 4 miles in length depicted by the black line.

LANDFIRE data were not produced to model severe conditions like high winds, but adjustments can be easily made to make the data adaptable to the situation. The spread of the Napau Fire on the 17th of March was under calm or more normal wind conditions. The simulation (Figure 22) for the 17th uses the southwestern perimeter from March 16th as its ignition source, the 10 minute average wind speed, and an 8 hour burn period as inputs on the standard download LF 2001 landscape file.

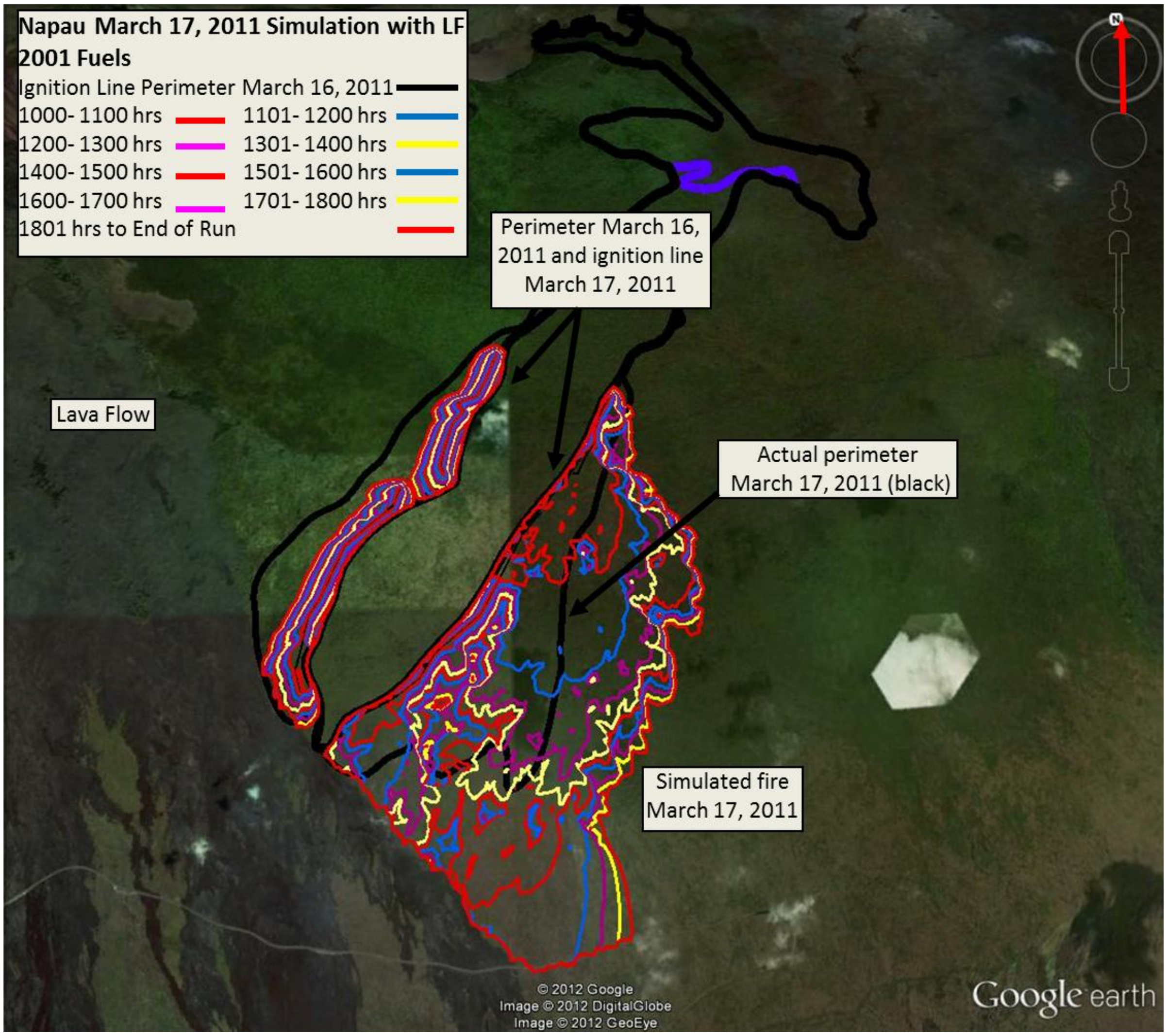

Figure 22 - Napau Simulated Fire Spread LF 2001 Landscape March 17, 2011. The fire extended nearly 4 miles in length depicted by the black line.

In the simulation above, the model under predicts the northwest portion of the fire perimeter and over predicts the southeast side of the fire spread. Fuel Model SH3 comprises all of the area to the northwest of the March 16th perimeter whereas on the southeast side the grass models of GR4 and GR3 are involved with SH3.

The LF 2008 fuels data with respect to FBFM40 are spatially the same as LF 2001 except for where the previous recent fire disturbances were considered high severity and the FBFM40 transitions to a GR1. This transition occurs from several fuel models, most prominently SH3, GR4, and GR3. The spatial arrangement of the FBFM40 for LF 2001 along with the severities of the disturbances between 2001 and LF2008 are shown in Figure 23 and Figure 24, respectively.

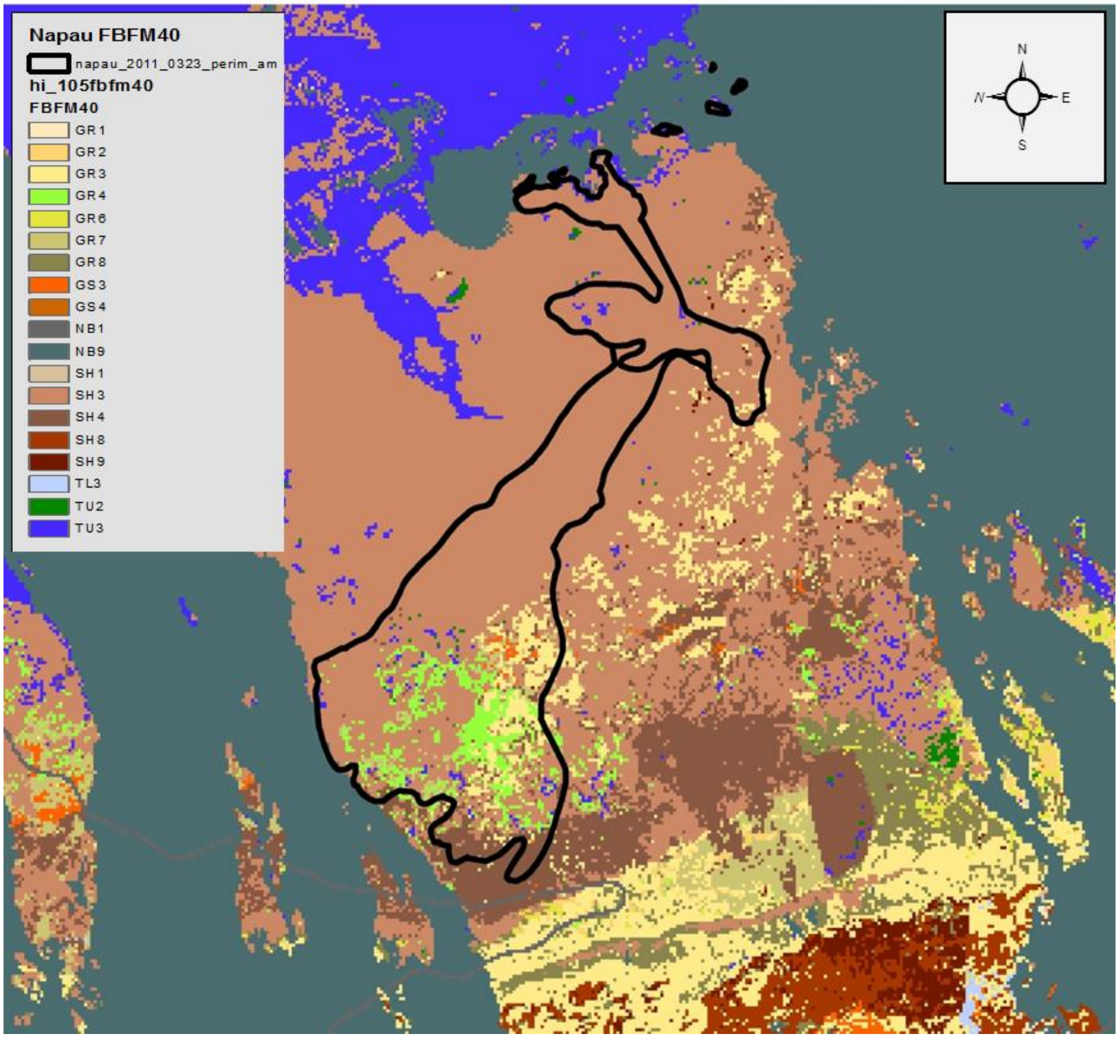

Figure 23 - Napau Fire Area LF 2001 FBFM40. The fire extended nearly 4 miles in length depicted by the black line.

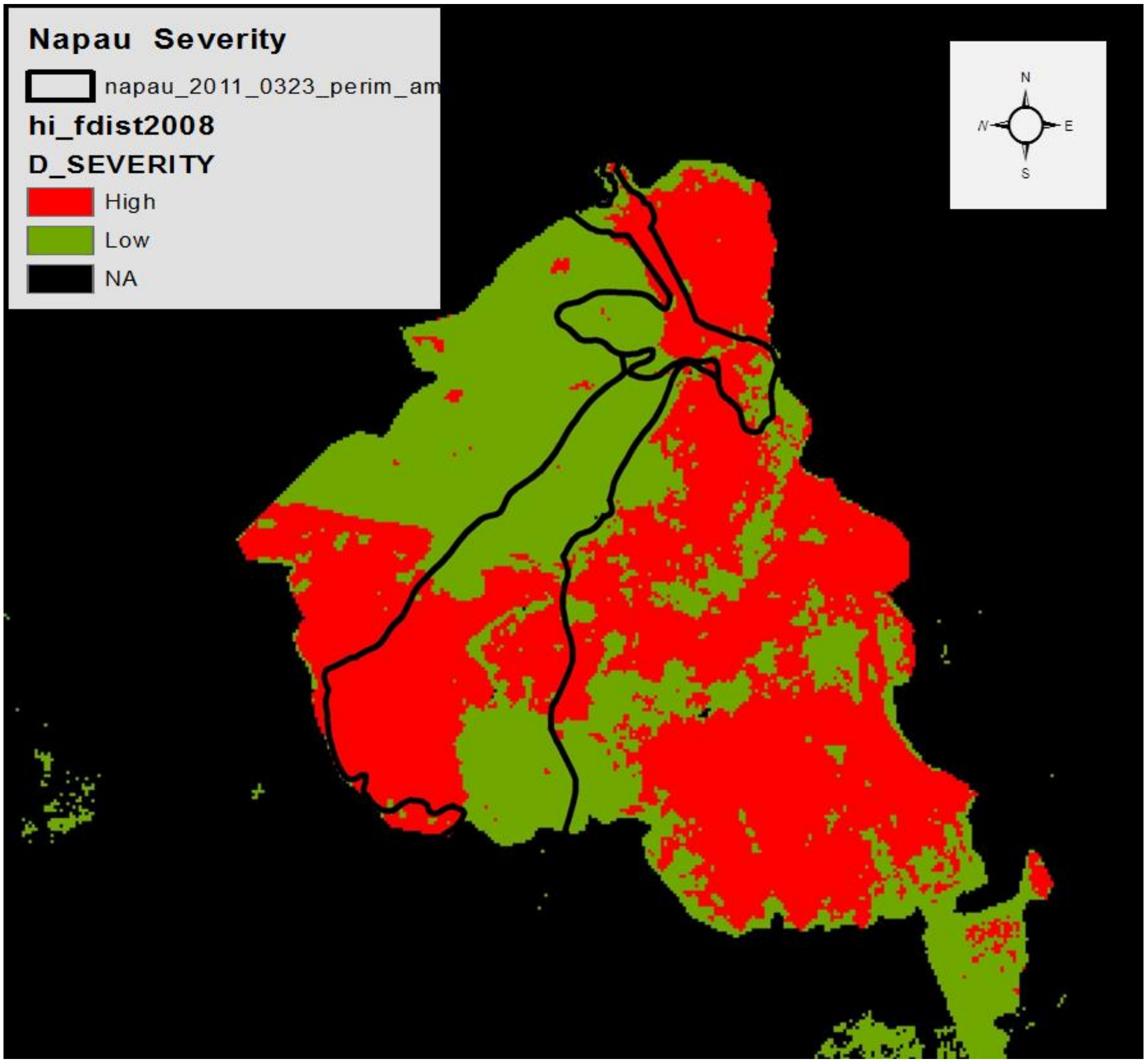

Figure 24 - Fire Disturbance Severity from LF 2001 to LF 2008. The fire extended nearly 4 miles in length depicted by the black line.

The simulation on the LF 2008 landscape, displayed below, has the CBH reduced to < 1 m and the same conditions with fuel moisture, burn period length, mid-point wind speed, and ignition line as was used in the LF 2001 March 16th simulation. In Figure **25**, the simulated fire spread slows where the fuel model transitions occur due to previous high severity fire disturbance.

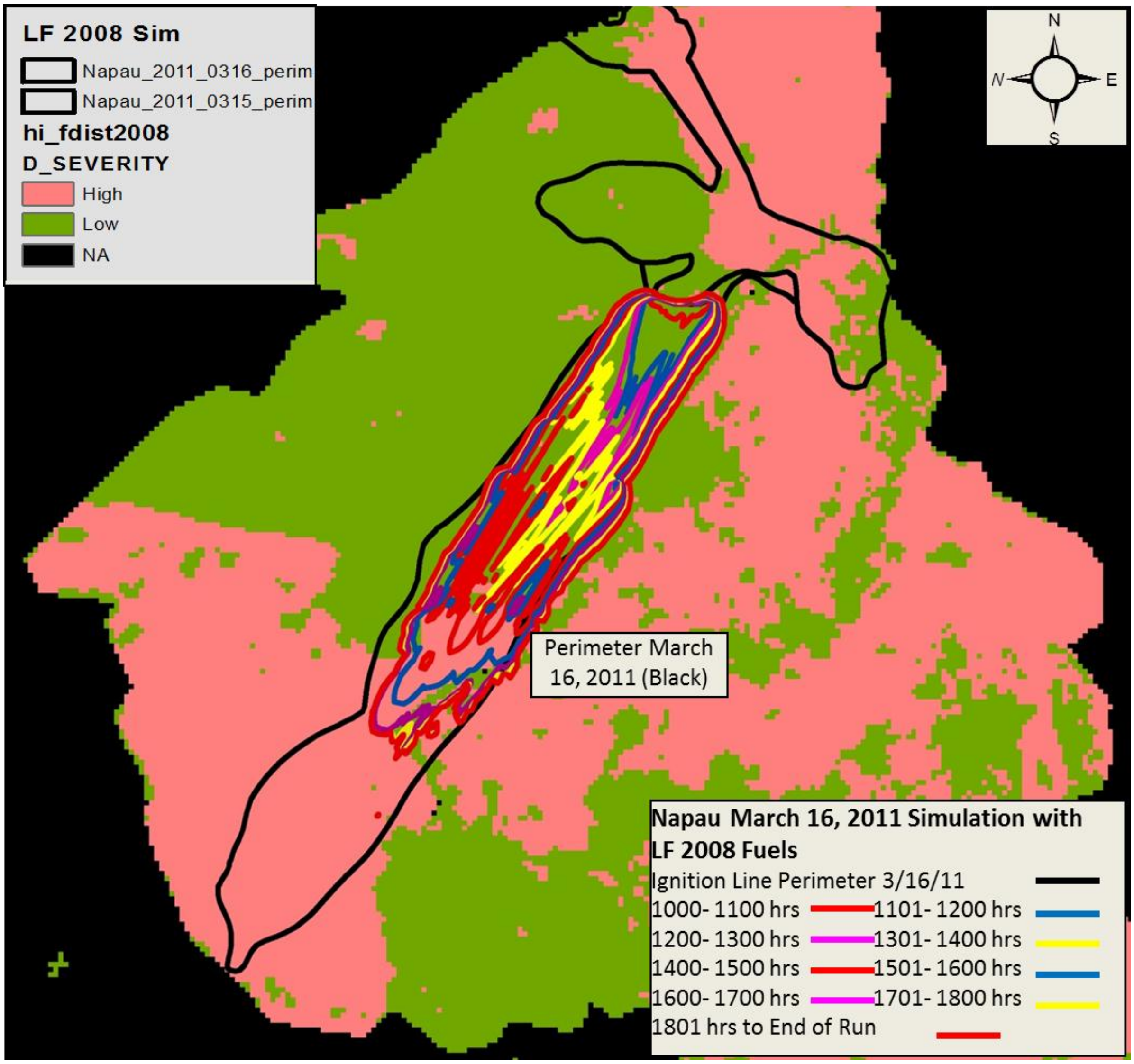

Figure 25 **-** The simulation on the LF 2008 landscape. The fire extended nearly 4 miles in length depicted by the black line.

The Napau Fire simulations show the effects of the updated fuel layers on fire behavior modeling applications. They also show that though vegetation in these landscapes are not well represented by standard fuel models, modifications to the input data can be made that provide a reasonable means to model fire behavior in Hawai'i.

4.0 LF 2001/2008 Organization

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5.0 Disclaimers

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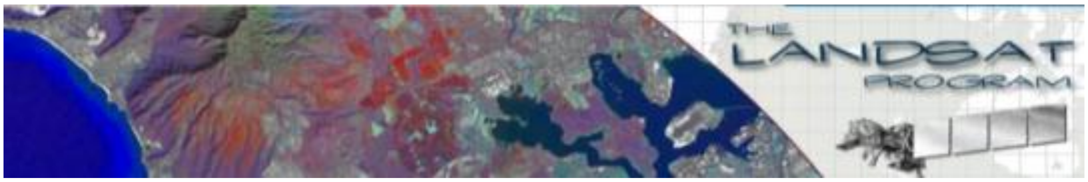
LF is not obligated to provide updates to the data herein, as they are and shall remain consistent with those used to develop the LF Program products. However, the LF Program will, at its discretion, continue using these and previously supplied and sampled data to update and improve future versions of LF products. Users of these data are requested to inform the LF Program of significant errors to assist with product maintenance activities. Please send your feedback to helpdesk@landfire.gov.

6.0 Additional Information

This section lists some, but not all, partners that the LF Program works with and relies on for information and data.

6.1 Landsat



The Landsat program within USGS is a critical partner in the development of LF data products. The 30-meter Landsat imagery constitutes the foundation upon which all data layers were mapped as well as updated. When LF began in 2004, Landsat data greatly increased costs associated with the development of LF data products. Now that these data are free, costs have decreased and data improvement opportunities similar to the LF 2008 update process are expanding.

6.2 Forest Inventory Analysis

USDA

FOREST SERVICE U S DEPARTMENT OF AGRICULTURE

The FIA Program of the USFS provides key information about America's forests. FIA provides a continuous forest census and reports on status and trends in forest area and location; in the species, size, and health of trees; in total tree growth, mortality, and removals by harvest; in wood production and utilization rates by various products; and in forest land ownership. Given the confidentiality of the FIA data, LF has a memorandum of understanding and supports an FIA employee who works with the FIA data, enabling LF to use this key resource. FIA has changed processes and procedures from a periodic survey to an annual survey and by expanding the scope of data collection to include soil, under story vegetation, tree crown conditions, Coarse Woody Debris (CWD), and lichen community composition on a subsample of plots. LF will evaluate these data sets in the continual process to improve and update the LF data products.

6.3 National Agricultural Statistics Service

NASS provides valuable agriculture data for the entire United States. These data were extremely useful in assisting to delineate burnable and non-burnable agricultural lands. LF 2001/2008 used NASS data to refine the burnable/non-burnable lands data. LF and NASS will continue to work together in the future on additional LF data product improvements.

6.2 Multi-Resolution Land Characteristics Consortium National Land Cover Database

The Multi-Resolution Land Characteristics Consortium (MRLC) is a group of Federal agencies that coordinates and generates consistent and relevant land cover information at the national scale for a wide variety of environmental, land management, and modeling applications. The creation of this consortium (the LF Program is a member) has resulted in the mapping of a comprehensive land cover product, termed the NLCD (Homer et al. 2004), which is based upon a decadal composite of Landsat satellite imagery and other supplementary data sets.

LF has leveraged the MRLC NLCD2001 land cover product with the development of LF National (circa 2001) data and works to promote nationally complete, current, and consistent data across the Nation.

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7.0 Glossary

FARSITE—Fire Area Simulator, a fire behavior and growth simulator

Fire Effects—The physical, biological, and ecological impacts of fire on the environment (National Wildfire Coordinating Group, 2005).

Fire Occurrence Database—A collection of information about fires including elements such as, date, location, acres, cause, etc.

Landsat Imagery—Thematic Mapper and Enhanced Thematic Mapper Plus image data from the Landsat 5 and Landsat 7 satellites, respectively. Image scenes have a footprint area of approximately 34,000 square kilometers and a pixel resolution of 30 meters.

Monitoring Trends in Burn Severity—Relevant spatial and non-spatial fire data are mapped by the MTBS project. Data elements include the latitude/longitude of the centroid of the MTBS burn scar perimeter.

Normalized Burn Ratio—a index similar to the Normalized Difference Vegetation Index. The primary difference is that NBR integrates the two Landsat bands that respond most, but in opposite ways to burning. The Landsat Thematic Mapper/Enhanced Thematic Mapper Plus bands used to calculate NBR are Band 4 and Band 7. The NBR is calculated as follows: NBR = (4 - 7) / (4 + 7).

Prescribed Fire—Any fire ignited by management actions to meet specific objectives (National Wildfire Coordinating Group 2005).

Remote Sensing Landscape Change— A process composed of four main elements. These are: 1) acquisition and compilation of field data; 2) wildfire burn mapping, as being conducted by the MTBS project; 3) updating and analysis using the VCT; and 4) mapping and incorporation of subtle intra-state changes, such as those related to insects and disease.

Spatial Resolution—The areal extent of the smallest unit, pixel, or feature that can be resolved on an image, map, or surface. Typically expressed as a measure of distance – for example, a 30-meter pixel – but can also be expressed as a unit of area.

Vegetation Change Tracker— The VCT is an automated and highly efficient algorithm for mapping changes in forest cover. The algorithm uses Landsat time series stacks, which are defined as sequences of Landsat images with a nominal temporal interval (for example, one image every year or every two years) for a particular location.

Wildfire—An unplanned, unwanted wildland fire, including unauthorized human-caused fires, escaped wildland fire use events, escaped prescribed fire projects, and all other wildland fires where the objective is to put the fire out (National Wildfire Coordinating Group 2005).

Wildland Fire—Any non-structure fire that occurs in the wildland. Three distinct types of wildland fire have been defined and include wildfire, wildland fire use, and prescribed fire (National Wildfire Coordinating Group 2005).

8.0 Acronyms

8.1 Acronyms for Agencies and Organizations

Agencies and Organizations	
BIA – Bureau of Indian Affairs	BLM – Bureau of Land Management
DOI – Department of the Interior	FWS – U. S. Fish and Wildlife Service
NASS – National Agricultural Statistics Service	NPS – National Park Service
NS – NatureServe	TNC – The Nature Conservancy
USDA – United States Department of Agriculture	USFS – U. S. Forest Service
USGS – U.S. Geological Survey	

8.2 Acronyms for Terms, Information, and Systems

Terms, Information, and Systems	
AK – Alaska	BARC – Burned Area Reflectance Classification
BpS – Biophysical Settings	CBD – Canopy Bulk Density
CBH – Canopy Base Height	CC – Canopy Cover
CFA – Crown Fire Activity	CFFDRS – Canadian Forest Fire Danger Rating System
CH – Canopy Height	CONUS – Conterminous United States
CWD – Coarse Woody Debris	DDS – LANDFIRE Data Distribution Site
DWM – Downed Woody Material	EDNA – Elevation Derivatives for National Applications
ERC – Energy Release Component	ESP – Environmental Site Potential

EVC – Existing Vegetation Cover	EVH – Existing Vegetation Height
EVT – Existing Vegetation Type	FBFM13 – Fire Behavior Fuel Model 13, Anderson
FBFM40 – Fire Behavior Fuel Models 40, Scott and Burgan	FCCS – Fuel Characteristic Classification System
FERA – Fire and Environmental Research Applications Team – USFS	FFE – Fire and Fuels Extension
FIA – Forest Inventory and Analysis – USFS	FLM – Fuel Loading Models
FOFEM – First Order Fire Effects Model	FRCC – Fire Regime Condition Class (also known as LF Vegetation Condition Classes [VCC])
FRCCMT – FRCC Mapping Tool	FRG – Fire Regime Group
FVS – Forest Vegetation Simulator	GAP – Gap Analysis Program
GAP – Gap Analysis Program – USGS	GLM – General Linear Model
GR – Grass	GS – Grass-shrub
HI – Hawaiʻi	hrs – hours
HUC – Hydrologic Unit Code	IR – Infrared
LCP – FARSITE landscape file	LF – LANDFIRE
LFRDB – LANDFIRE Reference Database	LTSS – Landsat Time Series Stacks
MFRI – Mean Fire Return Interval	MRLC – Multi-Resolution Land Characteristics Consortium
MTBS – Monitoring Trends in Burn Severity	MTDB – Model Tracker Database
NBR – Normalized Burn Ratio	NC – North Central
NE – Northeast	NFDRS – National Vegetation Classification Standard
NLCD – National Land Cover Database	NVCS – National Fire Danger Rating System
PAD-US – Protected Area Database of the United States	PLS – Percent of Low-Severity fire

PM2.5 – total fine particulate matter emissions less than 2.5 micrometers in diameter	PMS – Percent of Mixed-Severity fire
PNW – Pacific Northwest	PRS – Percent Replacement-Severity fire
PSW – Pacific Southwest	QA/QC – Quality Assurance / Quality Control
RAVG – Rapid Assessment of Vegetation Condition after Wildfire	RAWS – Remote Automated Weather Station
RMT – Refresh Model Tracker (LF 2001/2008)	RSLC – Remote Sensing of Landscape Change
SC – South Central	SCLASS – Succession Class
SE – Southeast	SH – Shrub
SOW – Statement of Work	SSURGO – Soil Survey Geographic Database
SW – Southwest	TL – Timber litter
TU – Timber-understory	VCC – Vegetation Condition Class formerly known as LF FRCC
VCT – Vegetation Change Tracker	VDDT – Vegetation Dynamics Development Tool
VDEP – Vegetation Departure Index formerly known as LF FRCC Departure Index	VTDB – Vegetation Transition Data Base
WBS – Work Breakdown Structure	WFAT – Wildland Fire Assessment Tool

9.0 References

Anderson, H.E., 1982, Aids to determining fuel models for estimating fire behavior: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, 22 p.

Barrett S, Havlina D, Jones J, Hann W, Frame C, Hamilton D, Schon K, Demeo T, Hutter L, Manakis J. 2010. Interagency Fire Regime Condition Class Guidebook. Version 3.0 [Homepage of the Interagency Fire Regime Condition Class website, USDA Forest Service, US Department of the Interior, and The Nature Conservancy]. [Online], Available: www.frcc.gov.

Comer, P., Faber-Langendoen, D., Evans, R., Gawler, S., Josse, C., Kittel, G., Menard, S., Pyne, M., Reid, M., Schulz, K., Snow, K., and Teague, J., 2003, Ecological Systems of the United States: A Working Classification of U.S. Terrestrial Systems: NatureServe, 83 p.

ESSA Technologies Ltd., 2007, Vegetation Dynamics Development Tool User Guide, Version 6.0: Prepared by ESSA Technologies Ltd., 196 p.

Finney, M.A., 2004, FARSITE: Fire Area Simulator - Model Development and Evaluation: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 47 p.

Homer, C., Huang, C., Yang, L., Wylie, B.K., and Coan, M.J., 2004, Development of a 2001 National Land Cover Database for the United States: Photogrammetric Engineering and Remote Sensing, v. 70, no. 7, p. 829-840.

Homer, C.G., Ramsey, R.D., Edwards Jr, T.C., and Falconer, A., 1997, Landscape cover-type modeling using a multi-scene thematic mapper mosaic: Photogrammetric Engineering and Remote Sensing, v. 63, no. 1, p. 59-67.

Interagency Fire Regime Condition Class Guidebook, 2010, Version 3.0, Homepage of the Interagency Fire Regime Condition Class website, USDA Forest Service, US Department of the Interior, and The Nature Conservancy, Online.

Jones, J., and Tirmenstein, D., 2012, Fire Regime Condition Class Mapping Tool User's Guide: National Interagency Fuels, Fire, and Vegetation Technology Transfer Team, 114 p.

National Wildfire Coordinating Group, 2005, Glossary of Wildland Fire Terminology: Boise, Idaho, National Interagency Fire Center.

Ottmar, R.D., Sandberg, D.V., Riccardi, C.L., and Prichard, S.J., 2007, An overview of the Fuel Characteristic Classification System — Quantifying, classifying, and creating fuelbeds for resource: Canadian Journal of Forest Research, v. 37, no. 12, p. 2383-2393.

Reeves, M.C., Ryan, K.C., Rollins, M.G., and Thompson, T.G., 2009, Spatial fuel data products of the LANDFIRE Project: International Journal of Wildland Fire, v. 18, no. 3, p. 250-267.

Reinhardt, E., Lutes, D., and Scott, J., 2006, FuelCalc: A method for estimating fuel characteristics, in Fuels Management - How to Measure Success, Portland, OR, Proceedings, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, p. 273-282.

References

Schmidt, K.M., Menakis, J.P., Hardy, C.C., Hann, W.J., and Bunnell, D.L., 2002, Development of coarse-scale spatial data for wildland fire and fuel management: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 41 p.

Scott, J.H., and Burgan, R.E., 2005, Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel's Surface Fire Spread Model: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 72 p.

Scott, J.H., and Reinhardt, E.D., 2001, Assessing Crown Fire Potential by Linking Models of Surface and Crown Fire Behavior: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 59 p.

Scott, J.H., and Reinhardt, E.D., 2005, Stereo photo guide for estimating canopy fuel characteristics in conifer stands: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 49 p.